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3-inch Anti-Submarine Rocket
Report of Penetration Trials Against Representative Targets

A. G. M. Small

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ARMAMENT RESEARCH AND DEVELOPMENT ESTABLISHMENT

A.R.D.E. MEMORANDUM (P) 12/56

3-inch Anti-Submarine Rocket

Report of penetration trials against representative targets.

A.G.M. Small (P.5)

Summary

Full results are given and discussed of all known trials fired against land targets representing a submarine and using the 3-inch (3.25 inch outside diameter) rocket with various solid heads. The use of these results to assess the performance of other rockets is also discussed.

Approved for issue:

D.H. Chaddock, Principal Superintendent "P" Division.

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INTRODUCTION

1. This paper gives an account of all known penetration trials fired in connection with the development of solid-headed rockets designed to be launched from aircraft for the attack of submarines lying on the surface or submerged to schnorkel depth. The results of trials previously reported are repeated here for completeness and so that overall conclusions can be drawn: the bulk of the paper however relates to trials not yet reported.

2. All trials were fired with the so-called "3-inch" rocket motor body fitted with a variety of alternative solid heads and filled with whatever propellant charges were necessary to give striking speeds at the target representative of the striking speeds which would be obtained on the submarine after various lengths of underwater travel. All motors and heads were 3.25 inches outside diameter. The complete rocket was guided along a runway during acceleration, but was in free flight with the propellant all burnt on striking the target; this consisted of a plate or plates rigidly held in a target frame and capable of being set at any required angle to the direction of motion of the rocket at strike.

DEVELOPMENT OF THE 3-INCH INTERIM ANTI-SUBMARINE ROCKET

3. The wartime head fitted to the "3-inch" anti-submarine rocket was a 25 lb. solid ogival S.A.P. shot which scored some successes but gave an unreliable underwater trajectory. In October 1949, a requirement was placed for an improved rocket for the attack of submarines on the surface or submerged to schnorkel depth. Three different heads were tried: types B and C (see Figs. 1 and 2), which were of the double-cone type designed to give an upturning underwater trajectory, and type D (Fig. 3) which gave a straight underwater trajectory. These trials were fired in 1950/51 against a target consisting of a single plate 1-inch thick of "D" quality steel and were reported in Ordnance Board Proceedings Q6,765 and Q6,917; the results of the penetration trials (but not the underwater trajectory trials) are repeated in Table 1 of this paper. The trials showed that the underwater trajectory of rockets fitted with Type D heads was more reliable than that of those fitted with Types B and C, moreover the plate penetrating qualities of Type D were found to be better at high angles of attack. At a striking speed on the target plate of about 600 ft/sec., the Type D head consistently passed through the target plate, or made a lethal hole in it, when attacking at an angle of 59 degs., whereas both the Types B and C heads failed at 59 degs. but made a lethal hole when striking at 52 degs. A lethal hole is defined as one of 2-inches diameter or of an equivalent area, and the angle of attack or strike is the angle between the axis of the rocket and the normal to the target plate at the point of strike. In the 1951 trial, fired with a striking speed of over 1,000 ft/sec., rockets with Type D heads did lethal damage to the target plate when striking at angles up to 64 degs. to the normal, but there were failures at 60 and 64 degs. and above. This was of interest, because successes had been obtained with the same head against the same target at an angle of 59 degs. and a striking speed as low as 507 ft/sec. It was concluded that a "limiting" or "skid off" angle existed above which consistent success was impossible even if the speed of strike was greatly increased; the graph Fig. 6 shows this very clearly, and the matter is discussed in para. 20.

4. As a result of these trials, the 3-inch rocket fitted with the Type D (Fig. 3) solid A.P. head was recommended for Service as an interim measure pending the solution of a longer term requirement. This 3.25 inch outside diameter rocket is now in service and is called the "3-inch Interim A/S Rocket".

5. During production of the inte[redacted]D heads for Service difficulties were experienced in keeping within the design hardness tolerances which control the heat treatment and plate penetrating qualities of the head. A further trial was therefore carried out in April, 1953 in which 24 heads were fired: some of these heads were within the hardness tolerances then allowed, and some were outside. There was no significant difference between the plate penetrating performance of heads inside and outside the tolerances; these were therefore extended to the values shown in Fig. 3 which therefore includes the hardness figures for all the heads fired; heads of this type fired in all the later trials reported in this paper were made to the same extended hardness tolerances. This head was also fired against the new double target described below, and the results are therefore included with those of the later trials in Table 2 and in the graphs (see Fig. 7).

6. The 1-inch "D" quality steel plate used in the 1950/51 trials was found to be brittle in cold weather and was not representative of the construction of modern submarine. The April 1953 trial just described and all subsequent trials were therefore fired against a double target consisting of two plates held parallel to each other and two feet apart but still capable of being set so that both were at any required angle to the path of the attacking rocket. The front or first plate struck in this target was 3 feet square of mild steel $\frac{3}{8}$-inch thick representing the superstructure of a submarine: the rear or second plate struck was 4 ft. x 3 ft. of "S" quality steel 1-inch thick and represented the pressure hull; both plates were flat.

7. A further difficulty in production was that of obtaining the STA-14(A) quality steel which was specified and had been used for the heads fired in all the trials. This steel was eventually obtained, but it was decided also to fire some heads made of STA-10 steel which was in better supply. The heads fired were exactly as shown in Fig. 3 and the heat treatment was in better supply. The heads fired were exactly as shown in Fig. 3 and the heat treatment was arranged to give the same hardness tolerances; the results obtained at this trial, which was fired in October and December 1954, were given in Table 3 and in the graph Fig. 8. Whereas heads made of the original steel did lethal damage to the 1-inch rear plate of the double target at a striking speed of 1000 to 1100 ft/sec. and up to an angle of attack of $66\frac{1}{2}$ degs., the head in the alternative steel failed in one case on striking at 1058 ft/sec. and 61 degs. It is recommended that this alternative steel (STA-10) should not be used unless a large number of additional heads made of it are fired and give as good results as those made of STA-14A which, in view of this failure, does not appear very likely.

FURTHER TRIALS WITH THE TYPE D (FIG. 3) HEAD

8. The Interim rocket fitted with the above head made of STA-14A steel was fired against the double-plate target representing a submarine in the April 1953 and October and December 1954 trials as a "Yardstick" for comparison with the other heads fired in these trials and also to get all possible information about the performance of the interim rocket itself at all speeds and angles of strike against this target. These trials were arranged in Ordnance Board Proceedings Q7,275 and Q7,658 and the results, most of which have not been reported before, are all given in Table 2 of this paper and in the graph Fig. 7. Much useful information was obtained and is discussed later in this paper.

TRIALS WITH DOUBLE-CONE HEADS FIGS. 4 AND 5

9. In September, 1950, Staff Requirement OR1099 was stated for a high performance air-to-ground and anti-submarine rocket; this is the "long-term" requirement which has been the subject of mathematical analysis in A.R.D.E. and also of certain trials. The relevant penetration trials are those with the double-cone heads shown in Figs. 4 and 5.

10. When the anti-submarine analysis was started, it was thought possible that a rocket with an upturning underwater trajectory would be recommended. It had, in this country, been usual to obtain such a trajectory with some type of double-cone head, and certain of these heads - the Types B and C of the 1950 trials - had been shown to be inferior to the type D head when fired against a single-plate target. It was not known however how the double-cone head would function against a representative double-plate target nor whether its performance in comparison with the Type D would be affected by using a finer angle to the front cone; it was therefore decided to fire a number of the heads shown in Fig. 4 in a comparative trial with the type D (Fig. 3); these trials were also arranged in O.B. Procs. Q7,275 and Q7,658.

11. It was decided to fire, at the same time, capped heads as shown in Fig. 5. Three different cap materials were tried: hardened steel, mild steel, and cast steel: all the caps were intended to remain in place during the underwater run - thus giving the required upturning trajectory - and the caps were therefore made very strong to resist the water entry shock. It was hoped that, on striking the target, the hardened and mild steel caps might assist penetration and that the cast steel cap would break away and leave what would then be a Type D head.

12. The results of all these firings with double-cone heads are given in Table 4 and in the graphs Fig. 9 (solid double cone), Fig. 10 (Hard Cap), Fig. 11 (Cast steel cap) and are compared with the Type D head results in Fig. 12. Because the OR1099 analysis was sufficiently advanced, before the conclusion of the trials, to show that an upturning trajectory would not be required for this particular weapon, the double-cone heads were only fired at high angles of attack. Results with the mild steel cap were poor and have not been shown in a graph.

13. It is concluded that the solid double-cone head is inferior to the Type D at angles of attack above 55-degs. and this confirms the inferiority of the Types Band C in the earlier trials. It is therefore unlikely that a solid double-cone head of any cone angle will ever give as good a performance as a Type D head at high angles of attack.

14. The capped heads were also inferior to the Type D, but this may be because of the particular design of cap used. The head with the hardened steel cap appeared to give slightly better results than the solid double cone and that with the cast cap gave a rather worse performance, but these differences may not be significant. It cannot be concluded that it is impossible to design a capped head which will equal the performance of the Type D, and it is recommended that any future designs should try much thinner caps in both hardened steel and cast steel; the head under the cap might also be cut back a little to give a larger diameter of flat.

REMARKS ON THE PERFORMANCE OF THE TYPE D (FIG. 3) HEAD

15. The plate-penetrating performance of an armour piercing shell or shot has commonly been predicted by means of the "Modified De Marre" formula which usually defines the "critical" conditions where lethal damage to the target is equally likely and unlikely:-

$$\frac{m\,v^2 \cos^2\theta}{d^3} = C\left(\frac{t}{d}\right)^{1.43}$$

Where m is the striking mass in lbs.
- v is the striking speed in feet/sec.
- d is the diameter of the projectile in inches
- t is the thickness of the plate in inches
- θ is the angle of attack or strike measured between the axis of the projectile and the normal to the plate at the point of strike.
- C is a constant which depends generally on the shape of the projectile head and the quality of the armour attacked. In the

case of trials, C is selected to give the best agreement with the experimental results.

16. The case of an anti-submarine rocket differs from that of an armour piercing shell or shot in certain important particulars:-

(a) The shell is usually required to attack hard armour of a thickness comparable to the shell diameter, and it relies upon a high speed of strike for success: the A/S rocket attacks a double target of shipbuilding plates, the total thickness of which is usually considerably less than the rocket diameter, but the rocket must defeat this target at a much lower striking speed and preferably at a higher angle of strike.

(b) There is no doubt about the value of the striking mass of a shell or shot, but in the case of a rocket, it is not yet known whether the value of "m" should include the mass of the whole rocket or that of the head only or if some intermediate value should be taken.

17. In the trials discussed in this paper, the masses of the heads and motors remained practically constant throughout, and the striking mass was taken as that of the whole rocket. (That is, head and motor = 42.6lbs.); had the mass of the head only been taken, it would simply have altered the value of "C" in De Marre and would not have affected the conclusions in any way. The difficulty noted in 16(b) above is only likely to produce serious error when, for example, De Marre, with the value for "C" found in the present trials, is used to predict the performance of a rocket having a materially different distribution of masses between the head and motor.

18. In Fig. 7, the full-line curve gives the best estimate which can be made from the experimental results of the striking speeds necessary to defeat the double target at all angles of attack up to the limiting angle which appears to be about 68 degs. The striking speed in this case is that with which the rocket strikes the front $\frac{3}{8}$ inch plate through which it always passes: the assessment of damage is that done to the rear 1-inch plate. In the same graph, the broken line is plotted using De Marre ($m = 42.6$ lbs. $d = 3.25$ ins. $t = 1\frac{3}{8}$ ins. and $\log C = 5.80$), and it will be seen that the agreement with the experimental curve is good: the value selected for "C" was of course that which gave the best agreement.

19. It is concluded that the De Marre equation, with a single value of C (for any given rocket and target) is applicable to the conditions of these trials over all angles of attack up to the limit. It was formerly believed that C was not a constant for a rocket but increased with the angle of attack, and the anti-submarine analysis used a variable C with values deduced from the rather scanty trial results available at the time. Fortunately, the constant value for C established by the more extensive trials now available is slightly lower in value than any C used in the A/S analysis which therefore slightly underestimates the penetrative qualities of the rockets analysed.

20. Reference has already been made in para. 3 to the "limiting" or "skid-off" angle. This is best shown in Fig. 6, from which it appears very likely that, with the Type D head, a striking speed of about 660 ft/sec. would have defeated the plate at an angle of attack of 61 degs. No consistently better performance was obtained by increasing the striking speed to well above 1,000 ft/sec., so that it is clear that there is a limit to the angle irrespective of speed.

21. For this particular 3.25 inch rocket fired against a single "D" steel plate 1-inch thick, the limiting angle with the Type D (Fig. 3) head appears to be about 61 degs: with the double-cone heads types D and C, the limiting angle lies between 52 and 59 degs., and has been taken as

55 degs. Against the double target of spaced plate, the limiting angles with the same rocket are less clearly marked but appear to be about 68 degs. with the type D and 58 to 60 degs. with the double-cone heads. It is concluded that the limiting angle is a function of head shape and is also materially increased by the presence of a fairly light plate in front of the main target plate. There is no evidence to suggest that, at high angles of attack, the front plate consistently turns the rocket towards the normal before it strikes the rear plate (compare columns (c) and (i) of Table 2 at angles of attack $61\frac{1}{2}$ to 70 degs.), and it is concluded that the most probable reason for the greater limiting angles obtained is that the front plate supports the rocket while it is attacking the rear plate and thus reduces the tendency to skid off.

POSSIBLE LINES OF IMPROVEMENT

22. The upturning underwater trajectory having been abandoned for the anti-submarine rocket, it becomes necessary to design the best possible straight runner. The best weight and calibre can only be decided by mathematical analysis and their determination are therefore outside the scope of this paper: the confirmation of the De Marre formula in its applicability to the problem and the fixing of the constant "C" should be helpful. There are however certain obvious characteristics which improve the performance of any A/S rocket:-

(a) Reduction of underwater drag which would give a greater striking speed after a given length of underwater run or would give the same striking speed after a longer run.

(b) Increase of the limiting angle of attack.

Both these characteristics are of great operational importance, because both tend to increase the effective target and to reduce the "dead arc" each side of the fore-and-aft line of the submarine in which no effective attack can be made.

23. Reduction of underwater drag in the case of the Type D head can be made by reducing the diameter of the nose flat: at present this flat is 0.4 calibres diameter, and this can probably be reduced to 0.34 calibres or even further without upsetting the underwater stability; the drag is proportional to the area of the flat, so that the reduction in drag would be substantial. Reduction of the nose flat diameter might however degrade the penetration performance, particularly in the case of smaller calibre heads which might become too weak for the attack of the $\frac{3}{8}$ plus 1-inch target. The problem can only be settled by further trials.

24. The superior penetration of the Type D head compared with the double cone head at high angles of attack is almost certainly caused by the "bite" which the edge of the flat nose of the head makes in the target plate at first contact; this bite is a deterrent to skid-off. It is just possible that, if the flat were replaced by a slightly concave surface, the bite and limiting angle might both be improved.

25. If the increase in limiting angle when attacking the double target was in fact caused by the support afforded to the rocket by the $\frac{3}{8}$-inch "superstructure" plate, then this support could only have been applied to the rocket motor body and transmitted through this to the head; the body tube and its joint with the head would therefore be subject to very high bending stresses when the head was attacking the 1-inch "pressure hull" plate at high angles to the normal. Examination of recoveries showed that this bending stress tore the head out of the body tube which belled open at the front end and usually bent. A stronger body tube and a stronger attachment to the head might maintain the support for a little longer and

thereby still further increase the limiting angle. Again, only trials can show.

APPENDICES

26. These contain trial dates and references (App. A), particulars of rockets, targets, and methods of recording and assessing (App. B), and a discussion of certain technical details of less general interest (including comments on tables 5 and 6 and Figs. 13 to 15) in Appendix C which also gives the recommended values for Log C in the De Marre equation.

APPENDIX A

LIST OF PLATE PENETRATION TRIALS FIRED ALSO REFERENCES

Note: References in paragraphs 1 and 2 are to the relevant trial reports from S.P.E.E. Pendine.

1. Trials Against a Single Plate of "D" Quality Steel 1 inch Thick

(a) February 1950: Three unhardened heads type C (Fig. 2) and three unhardened heads type D (Fig. 3). (All subsequent trials were fired with hardened heads) (KX.17/1/83 - 4/50 of 22.2.50).

(b) March 1950: Two each (hardened) heads types B, C and D (Figs. 1, 2 and 3) (KX.17/1/83 - 4/50 of 31.3.50).

(c) April 1950: Five each of types B and C and seven of type D. Also one each of types G and H (not included in tables or diagrams as G and H did not appear again) (KX.17/1/106 - 9/51 of 7.3.51).

(d) February/March 1951: Eleven type D. (KX.17/1/106 - 9/51 of 7.3.51).

2. Trials Against a Double Target Representing a Submarine

(a) April 1953: Twenty-four heads type D (Fig. 3) some of which were outside the hardness tolerances then allowed. (KX.17/1/218 - 58/53 of 16.6.53).

(b) October 1954: Following heads were fired;-

Fig. 4	8
Fig. 5 with hardened cap	8
Fig. 5 " mild steel cap	6
Fig. 5 " cast steel cap	7
Fig. 3 made of steel STA-10	8
Fig. 3 " " " STA-14(A)	8 (Type D)

(KX.17/1/153 - 51/52 of 13.12.54)

(c) December 1954: Twelve type D (Fig. 3) in STA-14(A) and two to Fig. 3 (KX.17/1/153B - 185/54 of 3.2.55) but made of STA-10.

3. Principal Ordnance Board Proceedings Relevant to Interim A/S Rocket

(a) O.B. Proc.Q.6,240 of October, 1949: States requirement (A.W.206) For the interim A/S rocket. Gives details of early discussion, correspondence, and proposed trials.

(b) O.B. Proc.Q.6,765 of Jan. 1951: Gives a summary of the 1950 trials with drawings of the heads fired, and recommends the truncated cone head for Service. Proposes trials with this head at higher striking speeds.

(c) O.B. Proc.Q.6,917 of June 1951: Gives a summary of the 1951 trial at higher striking speeds and closes the investigation.

(d) O.B. Proc.Q.7,283 of April 1952: Re-opens the investigation to cover firing interim Service heads made of alternative steel.

4. Principal O.B. Procs. Relevant to the Final A/S Rocket

(a) O.B. Proc.Q.6,686 of October 1950: Gives particulars of the new requirement (OR.1099) for a "high performance air to surface rocket for forward firing from aircraft" which covers the present A/S rocket development and the 1953/54 trials.

Appendix A (Contd.)

(b) O.B. Proc. Q.6,981 of July 1951: Gives particulars of D.N.O's stowage and safety requirements relevant to OR.1099.

(c) O.B. Proc. Q.7,275 of March 1952: Gives arrangements for the joint OB/CEAD trials fired in 1954 together with drawings of the double cone heads to be fired.

(d) O.B. Proc. Q.7,658 of March 1953: Gives revised instructions for the 1954 trials.

APPENDIX B

PARTICULARS OF ROCKETS, TARGETS AND METHODS OF RECORDING

1. Rocket Heads: These are shown in Figs. 1 to 5, and those in Figs. 1, 2 and 3 are referred to as Types B, C and D; of these Fig. 3 was tried in two different steels: STA-14(A) and STA-10. The heads in Figs. 4 and 5 have not been given type numbers and are referred to by the figure number only; in the case of Fig. 5, the material used for the cap is also stated.

2. Complete Rockets (Head and Motor) Dimensions and weight as follows:-

Diameter of body and head parallel	3.25 in.
Overall length with head Type D*	68 ins.
Weight of motor only, with charge all burnt and no saddles or tail fins	17.6 lb
Weight of head only	25.0 lb
Total striking mass of	42.6 lb

* 68 ins. with heads Figs. 1 and 4, 67 ins. with Fig. 2 and 70 ins. with Fig. 5.

3. (a) Full Charge Motors: All these were 'Motors, Rocket, Aircraft, 3 inch No. 1, Mark 3 or 4'. The Naval drawings of these motors are NOD. 6381 and 7155 respectively, and the other Service drawing numbers are DD(L)17864 and 20778.

(b) Reduced-Charge Motors: To obtain lower striking speeds, the Service motors described above were modified: the propellant charges were shortened, the space vacated by the charge was filled with a cardboard spacer tube, and the throat area of the venturi was reduced by fitting a "choke". This choke was kept in position during burning, but probably set forward along the empty body tube on striking the target. In the early trials the motor was simply called the "Reduced Charge" (shortened below to "RC"), but in the later trials the motors were distinguished by giving each a nominal speed which bore some relation to the actual striking speed obtained at Pendine.

(c) Table of Motors Used

Nominal Speed (ft/Sec)	Drawing	Charge weight (lb)	Throat diameter (ins)
1,000	Full charge Service motor as described	11.32	1.450
RC	Reduced charge used in 1950 DD(L)13977	6.25	0.980
750	D3(L)6014/GF/177 (Used in later trials)	7.65	1.190
600	" "	5.98	1.054
500	" "	4.94	0.958
400	" "	3.90	0.852

4. Single-Plate Target (Trials 1a to 1d). This was a single plate of 'D' quality steel about 4 ft. x 4 ft. x 1 inch thick. The plate was rigidly supported in a target frame and could be moved about a horizontal axis to give different angles of attack. 'D' quality steel has a low impact strength in cold weather and is now obsolete; the specification for this steel was:-

Not more than 0.3% of carbon
Ultimate tensile strength 37 to 44 tons/sq. inch
Least acceptable elongation 17% in 8 inches
Must pass bend and hot forge tests

5. Double Target representing a Submarine (Trials 2a to 2c). This consisted of two plates held rigidly in a target frame parallel to each other and so that the distance between them remained 2 ft. measured normal to their surfaces; both plates could be angled together about a horizontal axis to give any required angle of attack. The plate first struck - called the 'front' plate and representing the superstructure of the submarine - was of mild steel 3 ft. x 3 ft. x $\frac{3}{8}$ inch thick: the rear plate representing the pressure hull was 4 ft. x 4 ft. x 1 inch thick or 4 ft. x 3 ft. x 1 inch thick of 'S' quality steel which must conform to the following:-

Carbon content	....	0.20% (Max.)
Silicon "	....	0.35% "
Manganese	....	0.8% (Min.)
Sulphur	....	0.06% (Max.)
Phosphorous	....	0.06% "

Yield point	....	18.5 tons/sq.inch (Min.)
Ultimate tensile strength		30 to 34 tons/sq.inch

Elongation in an 8 inch length:-

(a) Test pieces over 10 lb .... 20% (Min.)
(b) " " " " .... 18% "

Must pass bend and hot and cold forge tests.

5. Recording

(a) Speed of strike on First Plate: Timed Electric pulses were produced as the rocket passed points on the runway: the resulting curve was extrapolated to give the speed on leaving the runway which was for practical purposes identical with the striking speed on the first plate of the target.

(b) Angle of Strike on Front Plate: The angle between the normal to the plate and the axis on the rocket runway was measured before firing each shot.

(c) Angle of Strike on Rear Plate of Double Target: Obtained from kinephotographs taken by a flank camera.

(d) Inter-plate Speed (Double Target Only): A laminated foil (two metal foils with insulation between) placed on the front face of the front plate produced a pulse when struck by the rocket head and started a microsecond counter: a second foil fixed over an inertia pellet on the rear face of the rear plate produced a second pulse when the rocket struck the front face of this plate and thus caused the pellet to pierce the foil: this stopped the counter which therefore recorded the time the rocket took in travelling from plate to plate.

(e) Exit Speed and Angle: Taken with a high-speed camera against a dimensioned background.

(f) Still Photographs: These were taken for each round of the target plate or plates and of the head if this was recovered.

7. Classification of Damage: In the case of the double target, the $\frac{3}{8}$ inch front plate was always holed, and the damage recorded is therefore that suffered by the 1 inch rear plate. This is classified as follows, and the abbreviations are those used in the tables:-

APPENDIX B (Contd.)

Perforation (Perf.): Head passed right through plate.

Lethal Hole (LH): Head did not pass through plate as far as is known, but the area of the hole made in the plate was equal to or greater than the area of a 2 inch hole.

Hole (H): As for a lethal hole but less than the equivalent area of a 2 inch hole.

Scoop (S): Where the attacked face has been scooped by a ricochet; the plate may or may not also be holed.

Stuck or Plugged: The head has holed the plate, but has remained stuck in the hole thus plugging it.

Of the above, the first two are assessed as "kills" and the others as "failures".

APPENDIX C

TECHNICAL DETAILS OF LESS GENERAL INTEREST

1. V^2 Method of Assessing Critical Striking Speed for Lethal Damage to 1 inch Plate. If for any given angle of attack, the loss of projectile energy in passing through the plate is constant, and if the projectile suffers no loss of mass, then the relation between the square of the exit speed and the square of the striking speed should be constant and capable of representation by a straight-line graph. In practice, shots are fired to strike at speeds well above the critical, and the resulting graph is extrapolated to the point where the exit speed would be zero: the corresponding striking speed should then be the critical value. This was tried, but the results were very inconsistent, probably because the rocket usually left its motor on the entry side of the plate so that the total mass at exit was much less than that at strike. The scheme was abandoned, and the critical speeds were assessed directly from the graphs Figs. 6 to 11.

2. Loss of Speed through $\frac{3}{8}$ inch Front Plate: Fig. 13 is based on a similar theory, but the square of the cosine of the angle of attack is introduced so that strikes at different angles can be compared. The result is a linear graph which rather surprisingly, passes very nearly through the origin; the exit speed after passing through the front plate can therefore be found with reasonable accuracy from the expression:-

$$\text{Exit speed} = 0.8623 \times \text{Striking Speed}$$

This equation is compared more directly with the experimental results in Fig. 14, and is used to assess the striking speed on the second plate of the double target when this speed is not actually recorded. There seems to be no systematic difference between the performance of the various heads in loss of speed through the front plate.

3. Attack of 1 inch Rear Plate of Double Target: The angle and speed of strike on this rear plate are known from the records or can be calculated as above, and, for the Type D head, there are sufficient results to assess the performance against this plate as a separate entity. These results are shown in Fig. 15 and a De Marre curve is fitted as before.

4. De Marre Constants: Curves calculated from De Marre have been drawn in three cases and particulars are given below; in all cases, m was taken as 42.6 lb. and d as 3.25 inches:-

Fig.	Head Type	Target	Value used for:- t	Log C
6*	D	Single 1" D steel plate	1 inch	5.868*
7	D	Complete double target	1.375 in.	5.800
15	D	Rear plate of double target	1 inch	5.868

Note* Whereas in Figs. 7 and 15 the value of the De Marre constant C was selected to agree best with the experimental results, this was not the case with Fig. 6 where there were insufficient points: in Fig. 6 the same value was used as in Fig. 15 to see whether any comparison was possible.

The agreement between the calculated and experimental curves in Figs. 7 and 15 is good, which shows that a constant value of log C can be used in any particular case for any angle up to the limit; it also shows that the difference between the values in Figs. 7 and 15 are significant (they correspond to C = 631,000 and 738,000 respectively.) The inference is that, at any given angle of strike, a double

target of $\frac{3}{8}$ inch mild steel plus 1 inch "S" quality steel can be defeated at a lower striking speed than can a single plate target of "S" steel $1\frac{3}{8}$ inch thick. This difference might have disappeared if the front $\frac{3}{8}$ inch plate had also been of "S" quality steel, but this is doubtful, and it may be that spaced plate is always easier to defeat than a single plate of the same total thickness and the same material. In Fig. 6, the success at 59 degs. and 507 ft/sec. suggests that the "D" quality steel plate is easier to defeat than the S quality for which the De Marre curve is drawn; this is probably true.

5. Mass of Saddles and Chokes: Neither have been included in the striking mass because:-

(a) Saddles: These are clamped to the motor body, and set forward on striking the target, thus probably assisting penetration by applying a forward force limited by the friction between the saddles and the motor. When the saddles themselves strike the plate, they are retarded or held by it and probably exert a backward pull on the rocket, again equal to the friction. The two results are assumed to cancel.

(b) Effect of a Choke in a Reduced Charge Motor: The choke weighs 2 lb and is assembled just in front of the venturi; it would tend to set forward when the rocket struck the first plate of the target and would have to reach somewhere near the base of the head before it could exert any appreciable force on the rocket. The time taken for the choke to move this distance inside the rocket would be much longer than the time taken for the rocket to travel from the first to the second plate, so that success or failure to penetrate would have resulted before the choke could affect the outcome. The mass of the choke can therefore be safely neglected.

6. Performance of Motors and Retardation on the 600 ft. Pendine Runway: Tables 5 and 6 are included for reference in arranging future trials; details of the motors are given in Appendix B.

TABLE 1: Results of 1950/51 Trials with Heads types B, C

(a) Date of Trial	(b) Round Number	Strike on 1 inch Target Plate (c) Angle to Normal	(d) Speed of Strike ft/sec.	Damage to 1 inch T (e) Description (Dimensions in inches)
		TABLE 1(a): Results with Head Type B (60 deg. Double Cone		
March 1950	5	$39\frac{1}{2}$	616	$3\frac{1}{4}$ x 3 hole and splits
"	6	40°	663	$3\frac{1}{4}$ x 3 " " "
April 1950	12	48°	NR	$3\frac{1}{4}$ x $3\frac{1}{2}$ " " "
"	14	48°	"	$4\frac{1}{2}$ x $4\frac{3}{4}$ " " "
"	16	48°	640	$3\frac{1}{4}$ x $5\frac{1}{4}$ " " "
"	10	52°	599	$10\frac{1}{2}$ x $2\frac{1}{2}$ hole and plate split in half
"	4	59°	609	Scoop only
		TABLE 1(b): Results with Head Type C (90 deg. Double Con		
Feb. 1950	1	3°	624	3 x 3 hole and splits
"	5	15°	611	$3\frac{1}{2}$ x $3\frac{1}{2}$ " " large split
"	6	30°	620	Scoop only. Target frame collapsed
March 1950	3	39°	649	$3\frac{1}{4}$ x $3\frac{1}{4}$ hole
"	4	$39\frac{1}{2}^\circ$	651	6 x $9\frac{1}{2}$ hole
April 1950	13	48°	620	4 x $4\frac{1}{4}$ hole and cracks
"	15	48°	609	$5\frac{1}{4}$ x 7 " "
"	17	48°	606	$3\frac{3}{4}$ x $4\frac{1}{4}$ " " "
"	11	52°	621	$9\frac{3}{4}$ x $\frac{3}{4}$ " " "
"	9	59°	633	Scoop only
		TABLE 1(c): Results with Head Type D (Truncated Cone Fig.		
Feb/March 1951	12	3°	1025	9 x $8\frac{1}{2}$ hole
Feb. 1950	2	3°	NR	7 x $3\frac{1}{2}$ " and split
"	4	15°	635	$9\frac{1}{2}$ x $6\frac{3}{4}$ "
"	3	$28\frac{1}{2}^\circ$	545	Scoop only. Target frame collapsed
Mar. 1950	1	30°	667	3 x 3 hole
"	2	40°	661	$3\frac{1}{4}$ x $3\frac{1}{4}$ "
April 1950	1	48°	504	$3\frac{3}{4}$ x $3\frac{1}{2}$ hole and split
Feb/Mar. 1951	9	$56\frac{1}{2}^\circ$	1031	29 x 12 " " large splits
"	10	57°	999	$13\frac{1}{2}$ x $5\frac{1}{2}$ "
"	11	56°	999	10 x 5 hole
April 1950	2	59°	507	$3\frac{1}{2}$ x $3\frac{1}{2}$ " and cracks
"	5	59°	609	$3\frac{3}{4}$ x $3\frac{1}{2}$ " " "
"	6	59°	647	$4\frac{3}{4}$ x $2\frac{1}{2}$ " and two large cracks
"	7	59°	618	$3\frac{1}{4}$ x $3\frac{3}{4}$ " and cracks
"	8	59°	617	3 x 2 hole and large crack
Feb/Mar. 1951	6	60°	1021	Centre of plate knocked out
"	7	60°	1099	Scoop only
"	8	63°	1008	Plate broken up
"	4	64°	1014	Centre of plate knocked out
"	5	64°	1025	Scoop only
"	3	67°	1022	Scoop only
"	2	76°	1029	Scoop only

KEY: Perf. = Perforation LH = Lethal Hole H = Hole (Smaller than lethal)

, and D (Figs.1 to 3) against a single 1 inch 'D' Steel Plate

arget Plate			(h) State of Recovered Head and Remarks
	(f) Equivalent Hole dia. (ins.)	(g) Assessment	
- Fig.1)			
	3	Perf.	Intact
	3	Perf.	Slight damage to point
	$3\frac{1}{4}$	Perf.	Cracked half along taper and slightly bent
	$4\frac{1}{2}$	Perf.	Most of taper broke off
	4	Perf.	Intact
	5	L.H.	NR
	-	S	NR
e - Fig.2)			
	3	Perf.)	Heads were not hardened, and no record remains of
	$3\frac{1}{2}$	Perf.)	their condition after recovery
	-	S)	
	$3\frac{1}{4}$	Perf.	Intact
	7	Perf.	Intact
	4	Perf.	Intact
	6	Perf.	Intact
	$3\frac{3}{4}$	Perf.	Intact
	4	LH	NR
	-	S	NR
3) - Service Interim Head			
	$8\frac{3}{4}$	Perf.	Very slightly bent, otherwise intact
	5	Perf.)	Heads were not hardened, and no record remains of
	8	Perf.)	their condition after recovery
	-	S	
	3	Perf.	Intact
	$3\frac{1}{4}$	Perf.	Intact
	$3\frac{1}{2}$	Perf.	Half taper broke off
	20	Perf.	Point bent round about 45 deg.
	7	Perf.	NR
	7	Perf.	Point damaged and bent
	$3\frac{1}{2}$	Perf.	Intact
	$3\frac{1}{2}$	Perf.	NR
	$3\frac{1}{4}$	Perf.	Head broke up
	$3\frac{1}{2}$	Perf.	Most of taper broke off
	$2\frac{1}{2}$	LH	NR
	20	Perf.	NR
	-	S	NR
	-	LH	NR
	20	LH	NR
	-	S	NR
	-	S	NR
	-	S	NR

S = Scoop NR = Not recorded or not recovered

Table 2: 1953/54 Results with The Interim Head (Type
against a Double-Plate Target Rep

(a) Date of Trial	(b) Round No.	Strike on $\frac{5}{8}$ inch Front Plate: (c) Angle to Normal	Strike on $\frac{5}{8}$ inch Front Plate: (d) Speed of Strike (ft/sec)	Damage to 1 inch Rear Plate: (e) Description (Dimensions in inches)	Damage to 1 inch Rear Plate: (f) Equival Hole di (ins.)
April 53	8	$\frac{1}{2}$"	350	Head stuck in plate $2\frac{3}{4}$" through, no cracks	Plugged
"	9	"	(350)	Head stuck in plate $3\frac{3}{4}$" through, no cracks	"
"	10	"	470	$3\frac{1}{4}$ dia. hole	$3\frac{1}{4}$
April 53	11	29°	460	Stuck in plate $8\frac{1}{2}$" through, two 4" cracks	Plugged
"	12	"	470	Hole $3\frac{1}{2}$	$3\frac{1}{2}$
Dec. 54	13	31°	336	$2\frac{1}{4}$ x $2\frac{3}{4}$ hole, head stuck	Plugged
"	14	"	470	$2\frac{3}{4}$ x 3 hole	$2\frac{3}{4}$
April 53	13	40°	790	$3\frac{1}{2}$ hole	$3\frac{1}{2}$
"	14	$40\frac{1}{2}^\circ$	830	$3\frac{3}{8}$ "	3[illegible]
"	15	"	995	$3\frac{3}{4}$ x $3\frac{1}{4}$ hole	$3\frac{1}{2}$
Dec. 54	9	43°	349	Point stuck in plate	Plugged
"	10	"	338	$1\frac{3}{4}$ x $1\frac{3}{4}$ hole	$1\frac{3}{4}$
"	11	"	(460)	$2\frac{1}{2}$ x 3 hole	$2\frac{3}{4}$
"	12	"	(460)	$2\frac{1}{2}$ x 3 hole	$2\frac{3}{4}$
April 53	16	$48\frac{1}{2}^\circ$	785	$3\frac{3}{4}$ hole	$3\frac{3}{4}$
"	17	48°	770	$3\frac{5}{8}$ x $3\frac{1}{4}$ hole	$3\frac{1}{2}$
"	18	48°	1005	$3\frac{3}{4}$ x $3\frac{1}{4}$ "	$3\frac{1}{2}$
Dec. 54	7	50°	469	3 x 3 hole	3
"	8	50°	437	Stuck in plate 2" through	Plugged
Oct. 54	19	$51\frac{1}{2}^\circ$	600	Scoop	-
"	20	"	599	$3\frac{1}{2}$ x $3\frac{3}{4}$ hole	$3\frac{1}{2}$
"	33	"	587	$3\frac{1}{4}$ x $4\frac{1}{4}$ hole	$3\frac{3}{4}$
"	18	"	788	4 x 4 hole	4
Dec. 54	5	55°	578	$3\frac{1}{2}$ x 4 hole	$3\frac{3}{4}$
"	6	"	585	Scoop and cracks through	-
Oct. 54	38	56°	790	$3\frac{1}{2}$ x $4\frac{3}{4}$ hole	4
"	43	57°	590	$3\frac{1}{2}$ x $3\frac{1}{2}$ hole	$3\frac{1}{2}$
April 53	19	59°	780	$3\frac{1}{4}$ hole	$3\frac{1}{4}$
April 53	20	$60\frac{1}{2}^\circ$	770	$7\frac{1}{2}$ x $2\frac{1}{4}$ hole	$4\frac{1}{2}$
Dec. 54	3	60°	788	Scoop	-
"	4	"	781	$3\frac{1}{2}$ x 5 hole	$4\frac{1}{4}$
Oct. 54	7	"	989	$3\frac{1}{4}$ x $4\frac{1}{4}$ hole. Wide $2\frac{1}{2}$ crack	4
April 53	21	$60\frac{1}{2}^\circ$	1005	$7\frac{1}{4}$ x $2\frac{3}{4}$ hole	$4\frac{3}{4}$
Oct. 54	1	60°	1087	7 x $3\frac{1}{4}$ hole	5
April 53	1	$60\frac{1}{2}^\circ$	1105	$5\frac{3}{4}$ x $3\frac{1}{4}$ hole and small crack	4

KEY: Perf. = Perforation LH = Lethal Hole H = Hole (Smaller than lethal)

NOTE: Figures in brackets are derived by averaging or other than by direct meas

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D Fig.3 - Truncated Cone in STA 14A steel)
resenting a Submarine

		(h)	Strike on 1 inch Rear Plate		Head after exit from rear plate	
ent a.	(g) Assessment	State of recovered head	(i) Angle to Normal	(j) Speed of Strike (ft/sec)	(k) Angle to Horizontal	(l) Exit Speed (ft/sec)
	Stuck	Intact	$(\frac{1}{2}^{\circ})$	(302)	-	-
	"	"	$(\frac{1}{2}^{\circ})$	(302)	-	-
	Perf.	"	$(\frac{1}{2}^{\circ})$	(405)	0°	180
	Stuck	Intact	(29°)	(397)	-	-
	Perf.	"	(29°)	(405)	$(30^{\circ}D)$	NR - very low
	Stuck	"	22°	(290)	NR	NR
	L.H.	"	17°	(405)	"	"
	Perf.	Intact	$37\frac{1}{2}^{\circ}$	(681)	$(30^{\circ}D)$	NR
	"	"	37°	(716)	0°	35[illegible]
	"	NR	44°	(858)	$(27^{\circ}D)$	871
	Stuck	Rest broke away leaving point	$26\frac{1}{2}^{\circ}$	(301)	NR	NR
	Hole	Intact (dropped between plates)	16°	(291)	"	"
	L.H.	Intact (in front of first plate)	24°	(397)	"	"
	L.H.	Intact (ditto)	$30\frac{1}{2}^{\circ}$	(397)	"	"
	Perf.	Intact	51°	(677)	$33^{\circ}D$	NR
	"	"	$47\frac{1}{2}^{\circ}$	(664)	$28^{\circ}D$	168
	"	"	$50\frac{1}{2}^{\circ}$	(867)	$18^{\circ}D$	891
	Perf.	Intact	40°	(404)	NR	NR
	Stuck	Half cone broke off on removal	45°	(377)	"	"
	Scoop	Most of cone broke up	$49\frac{1}{2}^{\circ}$	(517)	-	-
	Perf.	Intact	$44\frac{1}{2}^{\circ}$	(517)	NR	NR
	Perf.	Intact	44°	498	NR	NR - very low
	Perf.	Point broke off	$48\frac{1}{2}^{\circ}$	672	$10^{\circ}D$	506
	Perf.	Small piece off point	48°	385	NR	NR
	H & S	NR	$48\frac{1}{2}^{\circ}$	(504)		
	Perf.	NR	53°	699	$31^{\circ}D$	NR
	Perf.	Intact	49°	(509)	NR	NR - low
	Perf.	Intact	59°	(673)	$42^{\circ}D$	510
	LH & S	NR	61°	(664)	-	-
	Scoop	Intact	$59\frac{1}{2}^{\circ}$	(679)	NR	NR
	Perf.	NR	$58\frac{1}{2}^{\circ}$	735		
	Perf.	NR	58°	826	0°	702
	LH & S	Broke up	$58\frac{1}{2}^{\circ}$	(867)	-	-
	Perf.	Point broke off	$57\frac{1}{2}^{\circ}$	(937)	0°	412
	Perf.	Intact	$(60\frac{1}{2})$	(953)	$4^{\circ}D$	1042

S = Scoop   NR = Not recorded or not recovered   D = Nose down

urement

(1)

Table 2: 1953/54 Results with the Interim Head (Type D Fi
against a Double-Plate Target Representing a Subm

(a) Date of Trial	(b) Round No.	Strike on $\frac{3}{8}$ inch Front Plate		Damage to 1 inch Rear Plate	
		(c) Angle to Normal	(d) Speed of Strike (ft/sec)	(e) Description (Dimensions in inches)	(f) Equivaler Hole dia (ins.)
April 53	2	$61\frac{1}{2}^{\circ}$	985	$6\frac{1}{2}$ x $3\frac{1}{4}$ hole	4
April 53	22	$65\frac{1}{8}^{\circ}$	790	$5\frac{1}{2}$ x $1\frac{3}{8}$ hole and long scoop	3
"	3	65°	1100	4 x 2 hole and scoop	3
"	23	$65\frac{1}{2}^{\circ}$	1015	$5\frac{1}{4}$ x $2\frac{3}{4}$ hole and scoop	4
"	4	"	1105	5 x $2\frac{1}{4}$ " " "	$3\frac{1}{2}$
April 53	5	$66\frac{1}{2}^{\circ}$	1100	$4\frac{3}{4}$ x $3\frac{1}{4}$ hole	4
"	24	66°	1000	8 x 3 hole and scoop	5
April 53	7	69°	1000	Scoop only: no hole	-
"	6	70°	990	" " " "	-

KEY: As in previous page

NOTE: " " " "

.3 - Truncated Cone in STA-14A Steel)
arine (Contd.)

		(h) State of Recovered Head	Strike on 1 inch Rear Plate		Head after exit from rear plate	
t .	(g) Assess-ment		(i) Angle to Normal	(j) Speed of Strike (ft/sec)	(k) Angle to Horizontal	(l) Exit Speed (ft/sec)
	Perf.	Broke up	($61\frac{1}{2}^{\circ}$)	(849)	10° up	731
	LH & S	Broke up	$66\frac{1}{2}^{\circ}$	(681)	-	-
	"	NR	(65°)	(949)	-	-
	"	Broke up	67°	(875)	-	-
	"	NR	($65\frac{1}{2}^{\circ}$)	(953)	-	-
	Perf.	Intact	($66\frac{1}{2}^{\circ}$)	(949)	5°D	887
	LH & S	Broke up	65°	(862)	-	-
	Scoop	Intact	(69°)	(862)	-	-
	"	Intact	(70°)	(854)	-	-

(1)

Table 3: Results with Head Type D Fig.3 (Truncated Co[...]
Steel STA 10 against a Double Plate Type repre[...]

(a) Date of Trial	(b) Round Number	Strike on $\frac{5}{8}$ inch Front Plate (c) Angle to Normal	(d) Speed of Strike ft/sec	Damage to 1 inch Rear Plate (e) Description (Dimensions in inches)	(f) Equivale[...] Hole Di[...] (ins)
Oct 54	32	$51\frac{1}{2}^{\circ}$	588	$3\frac{1}{2}$ x 4 hole	$3\frac{3}{4}$
"	25	"	800	$3\frac{1}{4}$ x 4 hole	$3\frac{1}{2}$
"	17	"	1060	$3\frac{1}{2}$ x 4 hole and cracks	$3\frac{3}{4}$
Oct 54	45	56°	589	Head stuck at full diameter	Plugged
"	44	"	800	3 x $4\frac{1}{2}$ hole and cracks	$3\frac{3}{4}$
"	37	"	1039	3 x 5 hole and cracks	4
Oct 54	6	60°	984	2 x $3\frac{3}{4}$ hole and scoop	$2\frac{3}{4}$
Dec 54	1	"	1048	$3\frac{1}{2}$ x 7 hole and large cracks	6
	2	"	1084	$2\frac{3}{4}$ x 4 hole and scoop	$3\frac{1}{4}$
Oct 54	12	61°	1058	Scoop - cracked through	-

KEY: As Table 2
NOTES: As Table 2

e) in alternative materials:
enting a Submarine

nt a.	(g) Assessment	(h) State of Recovered Head	Strike on 1 inch Rear Plate (i) Angle to Normal	Strike on 1 inch Rear Plate (j) Speed of Strike ft/sec	Head after exit from Rear Plate (k) Angle to Horizontal	Head after exit from Rear Plate (l) Exit Speed ft/sec
	Perf	Intact	$44\frac{1}{2}^{\circ}$	494	NR	NR - very low
	Perf	Intact	$47\frac{1}{2}^{\circ}$	707	"	NR
	Perf	Intact	50°	926	"	NR - low
	Stuck	Slight damage to point	51°	496	NR	NR
	Perf	NR	54°	666	$5\frac{1}{2}$ down	542
	Perf	Intact	$54\frac{1}{2}^{\circ}$	958	4° down	877
	LH & S	Cone broke up	$58\frac{1}{2}^{\circ}$	811	NR	NR
	LH	NR	$59\frac{1}{2}^{\circ}$	(904)	NR	NR
	LH & S	Cone broke up	60°	(935)	NR	NR
	Scoop	NR	$56\frac{1}{2}^{\circ}$	1023	NR	NR

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TABLE 4:- Results with Double-Cone Heads: So

(a) Date of Trial	(b) Round Number	Strike on ⅜ inch Front Plate		Damage to 1 inch Rear Plate		
		(c) Angle to Normal	(d) Speed of Strike (ft/sec)	(e) Description (Dimension in inches)	(f) Equivalent Hole dia (ins.)	Ass
					Results with Soli	
Oct 54	13	50°	1022	3½ x 5½ hole	4½	Pe
"	30	51½°	575	Scoop	-	Sc
"	21	51½°	807	3½ x 3½ hole	3½	Pe
"	39	56°	780	3¼ x 4¼ hole	3¾	Pe
"	41	56°	783	Scoop	-	Sc
"	34	56°	1069	3½ x 5 hole	4½	Pe
"	2	60°	998	2 x 2 hole and scoop	2	LH &
"	8	60°	1004	Deep Scoop	-	Sc
					Results with Fig.	
Oct 54	14	50°	1039	3½ x 4 hole plus 5" crack	4¼	Pe
"	31	51½°	586	3 x 3½	3¼	Pe
"	22	51½°	797	3½ x 4½	4	Pe
"	40	56°	720	Scoop	-	Sc
"	42	56°	795	3¼ x 4 hole	3½	Pe
"	35	56°	1044	3¼ x 4¾ hole	4	Pe
"	3	60°	1080	2 x 3 hole and scoop	2½	LH &
"	9	61°	995	Scoop	-	Sc
					Results with Fig.	
Oct 54	15	50°	1062	3¼ x 8½ hole	5¾	Pe
"	23	51½°	799	Scoop	-	Sc
"	26	51½°	780	Scoop	-	Sc
"	28	51½°	784	Scoop	-	Sc
"	4	60°	1004	Scoop	-	Sc
"	10	61°	1005	Scoop	-	Sc
					Results with Fig.	
Oct 54	16	50°	1005	3¼ x 4 hole	3½	Pe
"	24	51½°	790	Scoop	-	Sc
"	27	51½°	802	3 x 4 hole	3½	Pe
"	29	51½°	790	Scoop	-	Sc
"	36	56°	1015	Scoop	-	Sc
"	5	60°	985	Scoop	-	Sc
"	11	61°	1064	3 x 6 hole	4½	Pe

KEY: As in Table 2
NOTE: As in Table 2

id (Fig.4), and Capped (Fig.5) with three cap materials

(g) essment	(h) State of recovered head	Strike on 1 inch Rear Plate (i) Angle to Normal	(j) Speed of Strike (ft/sec)	Head after exit from Rear Plate (k) Angle to Horizontal	(l) Exit Speed (ft/sec)
d Head Fig.4					
rf.	Both cones broke up	48°	909	0°	733
oop	Broke up, NR	49½°	503	NR	NR
rf.	Both cones broke up	46½°	706	NR	NR
rf.	Front cone broke up	52½°	648	38° down	NR
oop	Half front cone broke off	54½°	673	38° up	545
rf.	Front cone broke up	55½°	913	0°	757
S	Both cones broke up	57½°	924	50° up	625
oop	Point broke off	59°	(866)	39° up	707
5 Head with Hardened Steel Cap					
rf.	Cap NR, body broke up	45°	864	NR	NR
rf.	Cap NR, Slight damage to point of body	44°	(505)	NR	NR
rf.	Cap NR, half body cone broke off	47½°	665	NR	NR
oop	Cap NR, Slight damage to point of body	55½°	684	41° up	552
rf.	Cap NR, ditto	55½	730	NR	NR - very low
rf.	NR	54½	965	12° down	776
S	Broke up	58	(931)	NR	NR
oop	Cap NR, body point slightly damaged	59½	780	40° up	NR
5 Head with Mild Steel Cap					
rf.	Cap NR, body intact	53½	765	0°	823
oop	Cap NR, body intact slightly bent	52½	(689)	50° up	603
oop	Cap NR, body intact	51½	(673)	44° up	553
oop	Cap NR, body intact	55	(676)	NR	NR
oop	Cap flattened, body NR	57	735	NR	NR
oop	Cap NR, body intact	63½	812	32° up	737
5 Head with Cast Steel Cap					
rf.	NR	51½	814	10° up	656
oop	Cap NR, body intact	55	(681)	43° up	375
rf.	Cap NR, body intact	52	(692)	NR	NR
oop	Cap NR, body intact	56½	706	50° up	NR
oop	NR	60½	839	NR	NR
oop	Cap NR, body intact	58½	759	35° up	896
rf.	Cap NR, body intact	61½	667	14° down	725

(1)

TABLE 5: 1953/54 Results with Full and Reduced Charge Rocket Mot

Motor Type	Nominal Speed ft/sec	Number Fired in 1953/54 Trials	Mean Recorded Speed at end of Runway ft/sec.	Mean error ft/se
J	1000	35	1033	35.46
G	750	24 (plus one disregarded)T	790	8.92
K	600	10	588	5.50
I	500	6 (plus 2 NR)	463	9.44
H	400	4 (plus 1 NR)	343	6.25

Notes: * (i) For each type of motor, the arithmetic sum is found of the diffe
the result is divided by the number of motors in the group and t

T (ii) One motor in the 750 ft/sec. group was recorded as having a speed
may have been a mistake.

I (iii) The large mean error of the 1000 ft/sec motor may have been cause
observed in certain cases.

TABLE 6: Deceleration on the 600 feet Runway in the April 1953 T

This table is extracted from C.E.A.D.'s comments on trial 58/53 fired in April,
suggested that the table below may be of general application for rough estimates
is caused by friction between the rocket saddles and the runway and by air resist

Retardation of a rocket on the Pendine 600 - fe			
Speed of Rocket in ft/sec.	300	400	50
Retardation in ft/sec^2	27	38	5

Note: Retardation was only calculated for the Ap

(2)

<u>rs with 25 lb. Heads fitted fired on the 600 feet Pendine Runway</u>

н .	Remarks
I	)Motor heated to about $130^{o}F$ before firing to ensure that it would be all)burnt on the runway. Motor not heated " "

rences between the mean speed of the group and the actual speed of each motor;
e result is the mean error.

of 720 ft/sec.which was disregarded because it appeared to be quite exceptional and

by some reaching the end of the runway while they were still burning. This was

<u>rial</u>

1953. C.E.A.D.'s reference is D8(T)96 of 27.11.53, paragraph 6, where it is
f the thrust required with any rocket fired on this runway. The retardation
nce.

t Runway					
600	700	800	900	1000	1100
86	126	173	228	300	400

il 1953 trial for which additional records were supplied.

P5/8382/117 ROCKET HEADS USED IN PLATE TRIALS.

SHEET 1

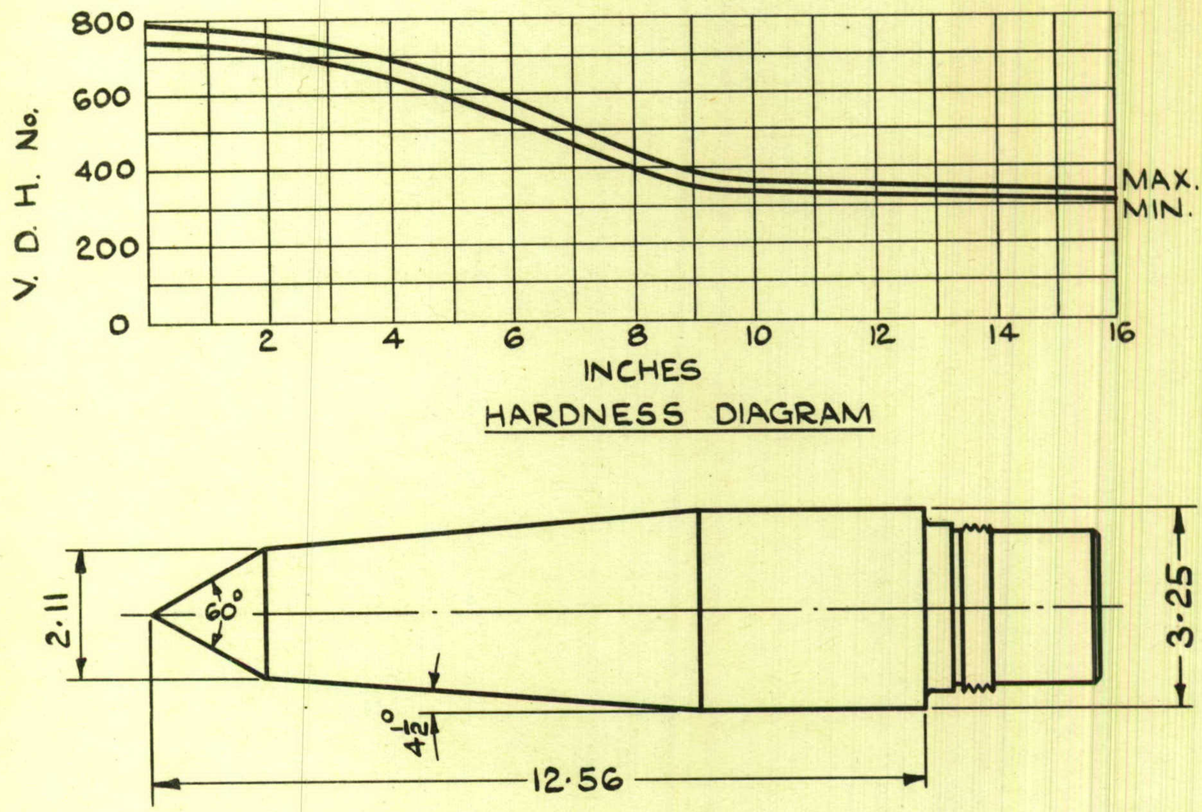


FIG. 1 FROM D. 8 (L) 3739 (16·1·50)

DIMENSIONS ARE IN INCHES

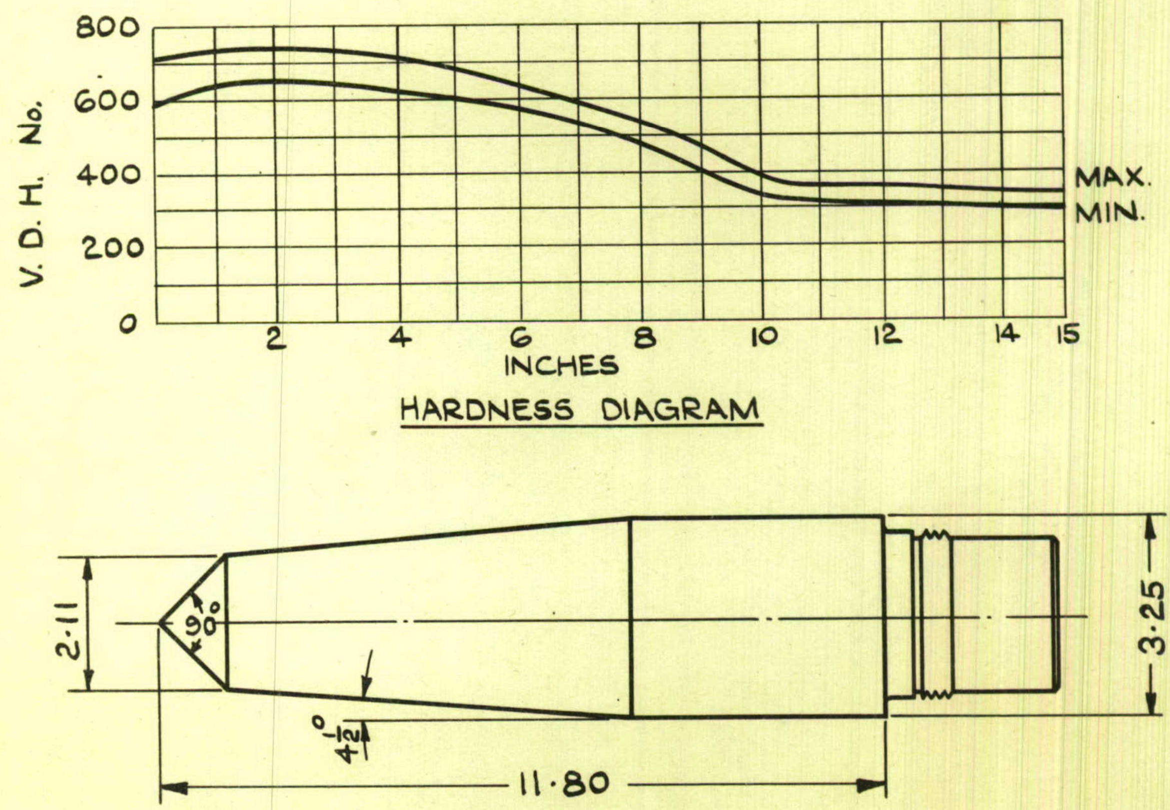


FIG. 2 FROM D. 8 (L) 3740 (16·1·50)

DIMENSIONS ARE IN INCHES

A.R.D.E. M. OF S.

P5/8382/117. ROCKET HEADS USED IN PLATE TRIALS.

SHEET 2

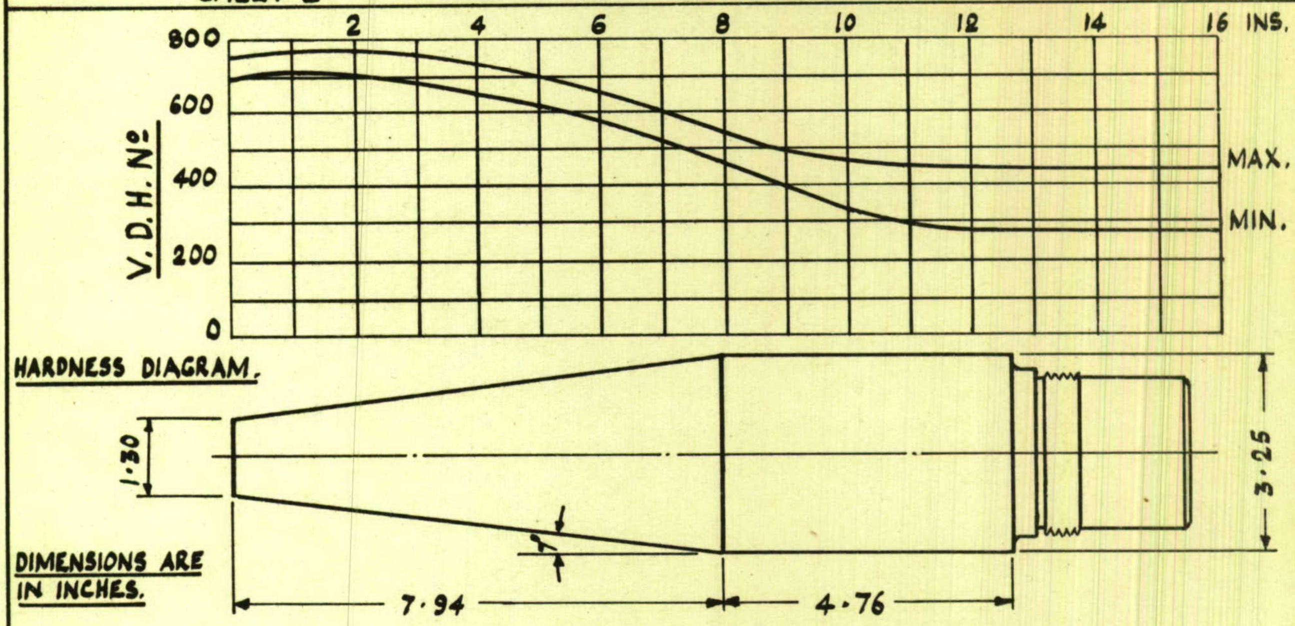


FIG.3. FROM N.O.D. 7826 SHEET 1 (13·4·53) SHEET 2 (13·8·53)

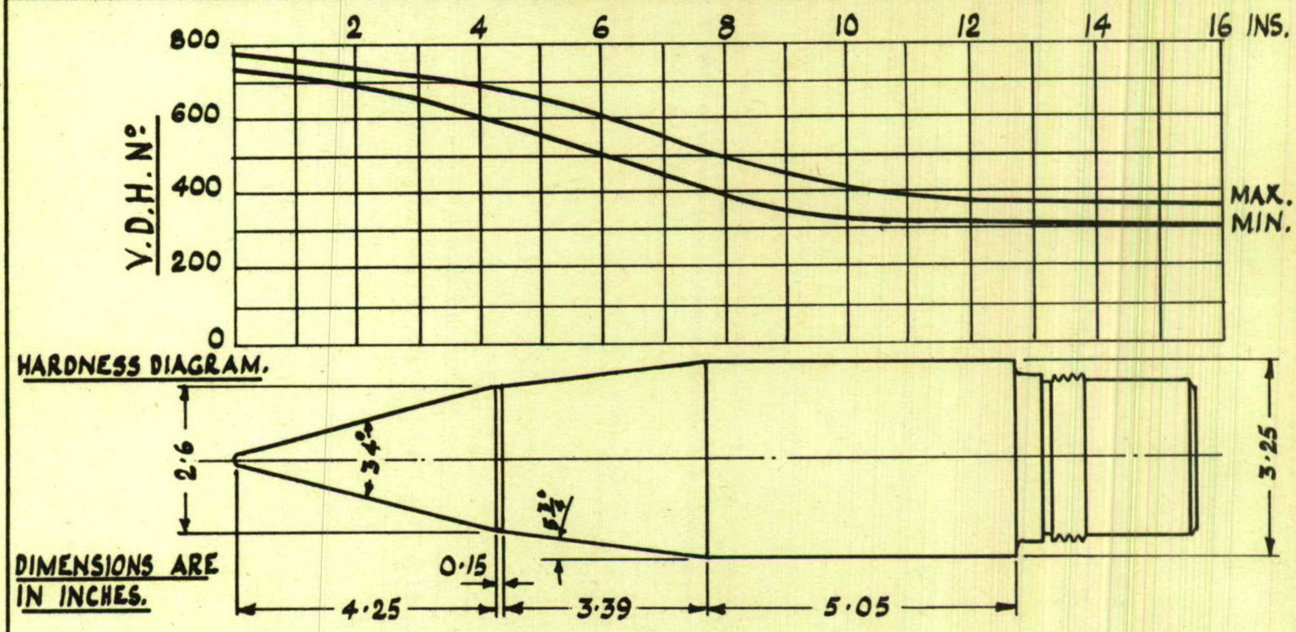


FIG.4. FROM D.8(L)5776/177 SHEET 1 (1·1·52) SHEET 2 (1·1·52)

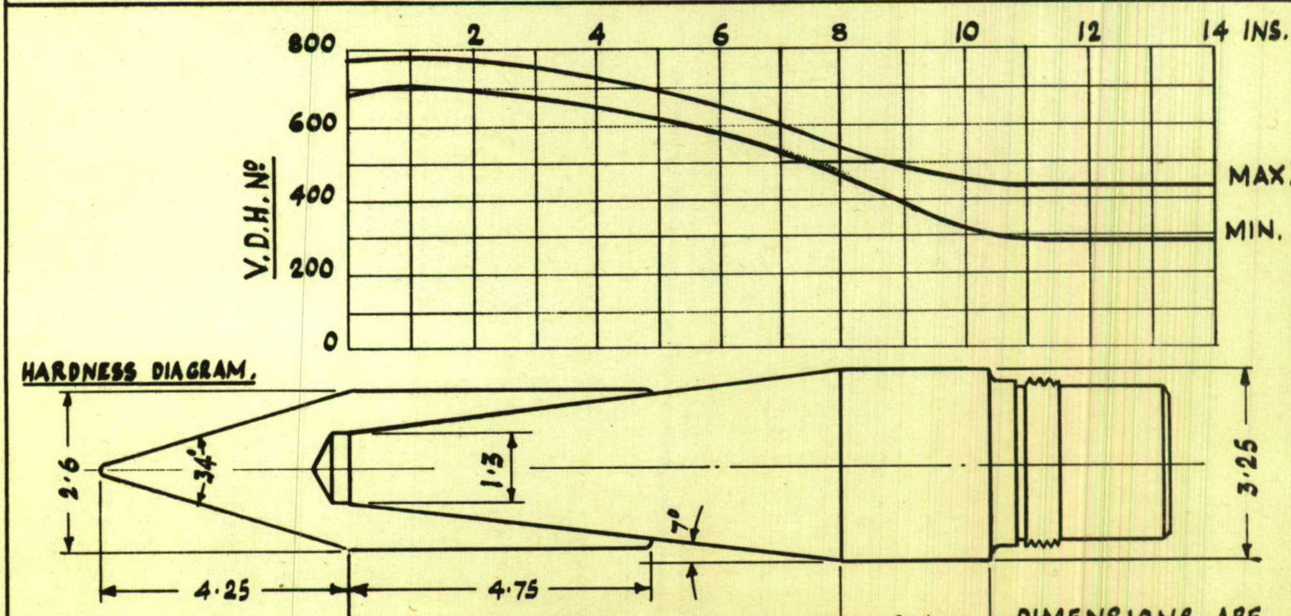
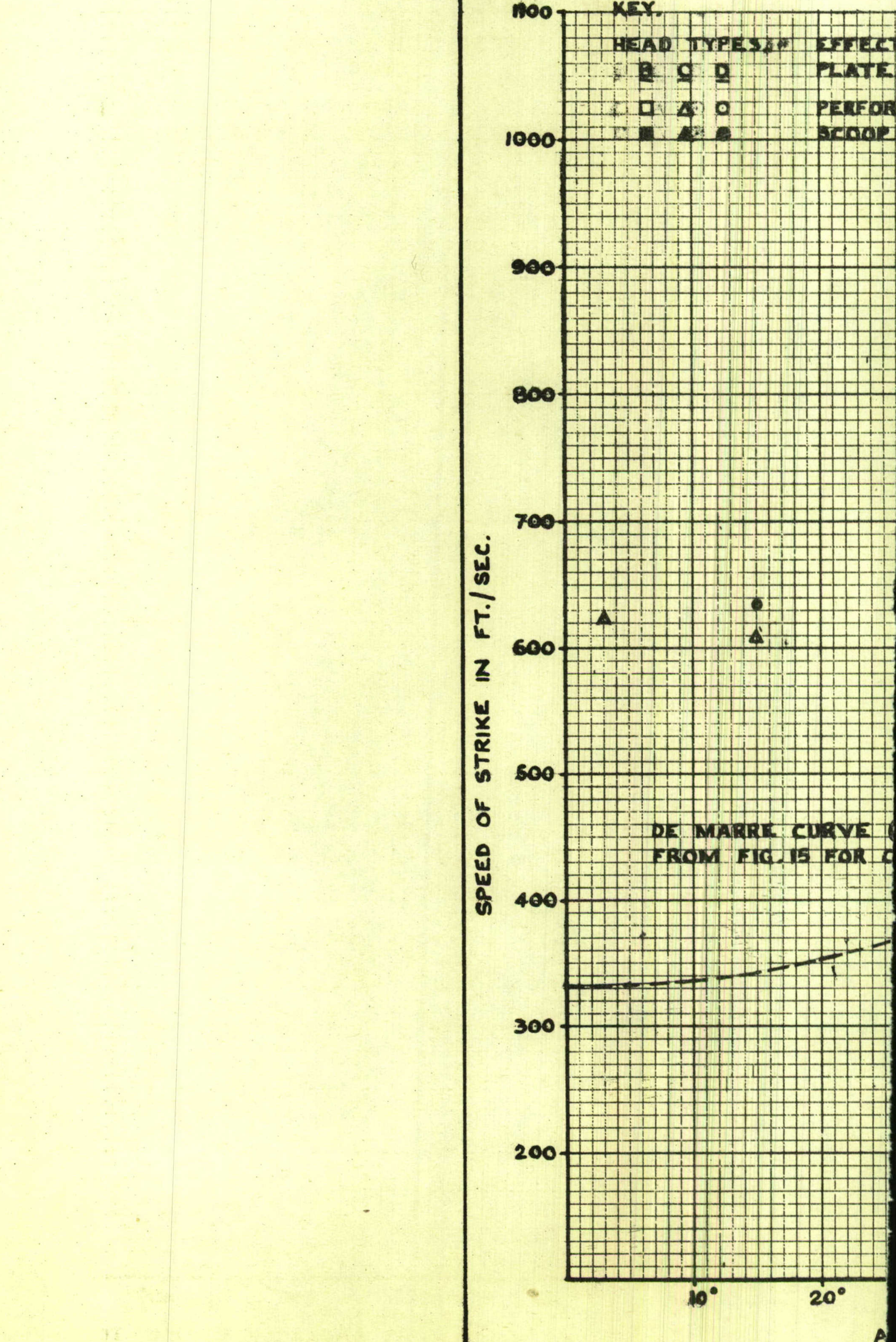


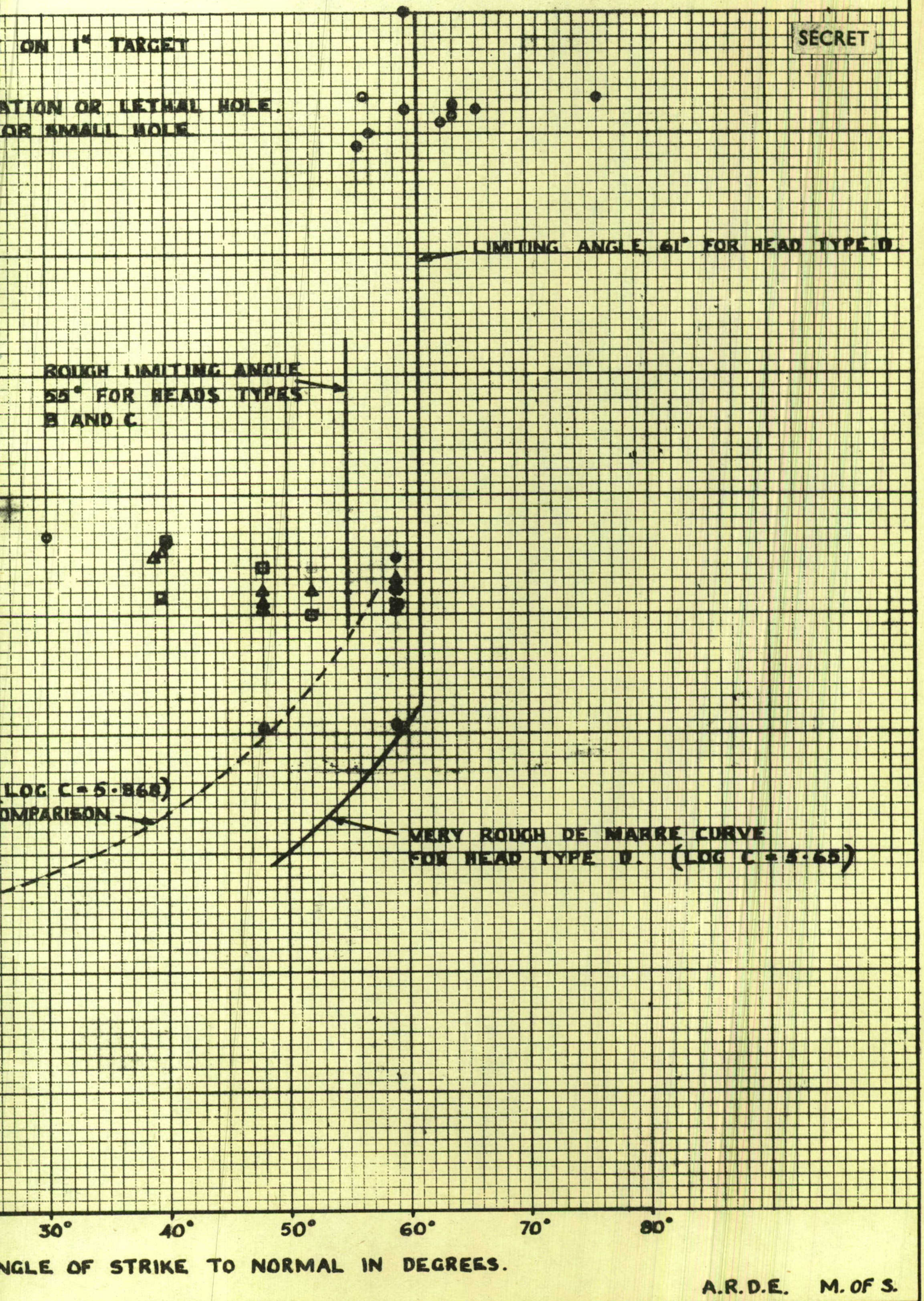
FIG.5. FROM D.8(L)5777/177 SHEET 1 (1·1·52) SHEET 2 (4·11·53)

(1)

TRIALS	HEAD	TARGE
1950/51 (TABLE 1)	TYPES B, C, & D.	SINGLE OF 1-1 'D' STE

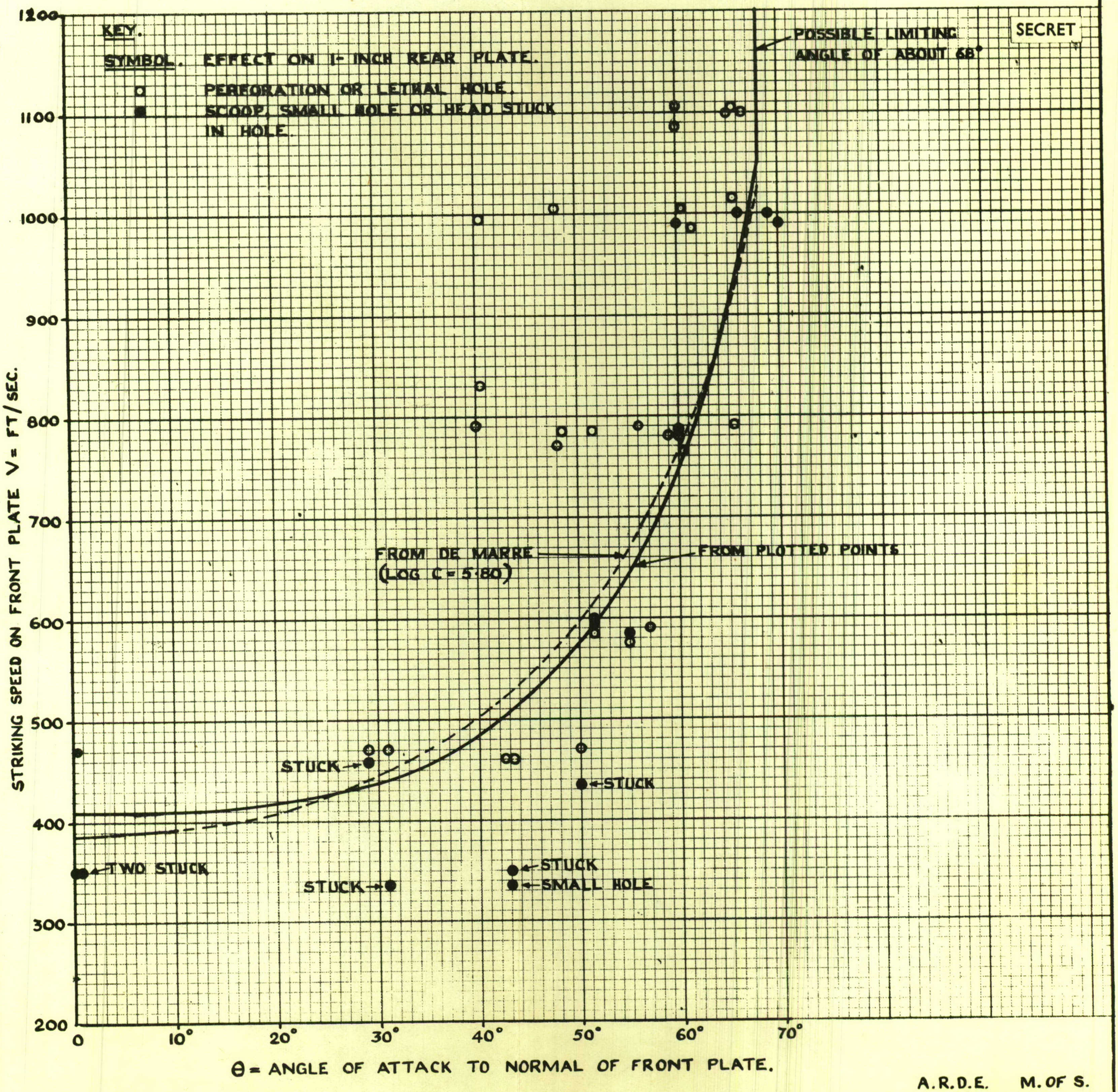


	GRAPH REPRESENTS	
LATE NCH EL	(i) LIMITING ANGLES FOR LETHAL DAMAGE WITH DIFFERENT HEADS AND ROUGH CURVE FOR TYPE D. (ii) DE MARRE CURVE AS IN FIG. 15 FOR COMPARISON.	FIG. 6



A.R.D.E. M. OF S.

TRIALS	HEAD	TARGET	CURVE REPRESENTS	
1953/54 (TABLE 2)	TYPE D IN STA. 14A STEEL	COMPLETE DOUBLE TARGET	LIMITING ANGLE AND CRITICAL STRIKING SPEED FOR LETHAL DAMAGE TO COMPLETE TARGET.	FIG. 7



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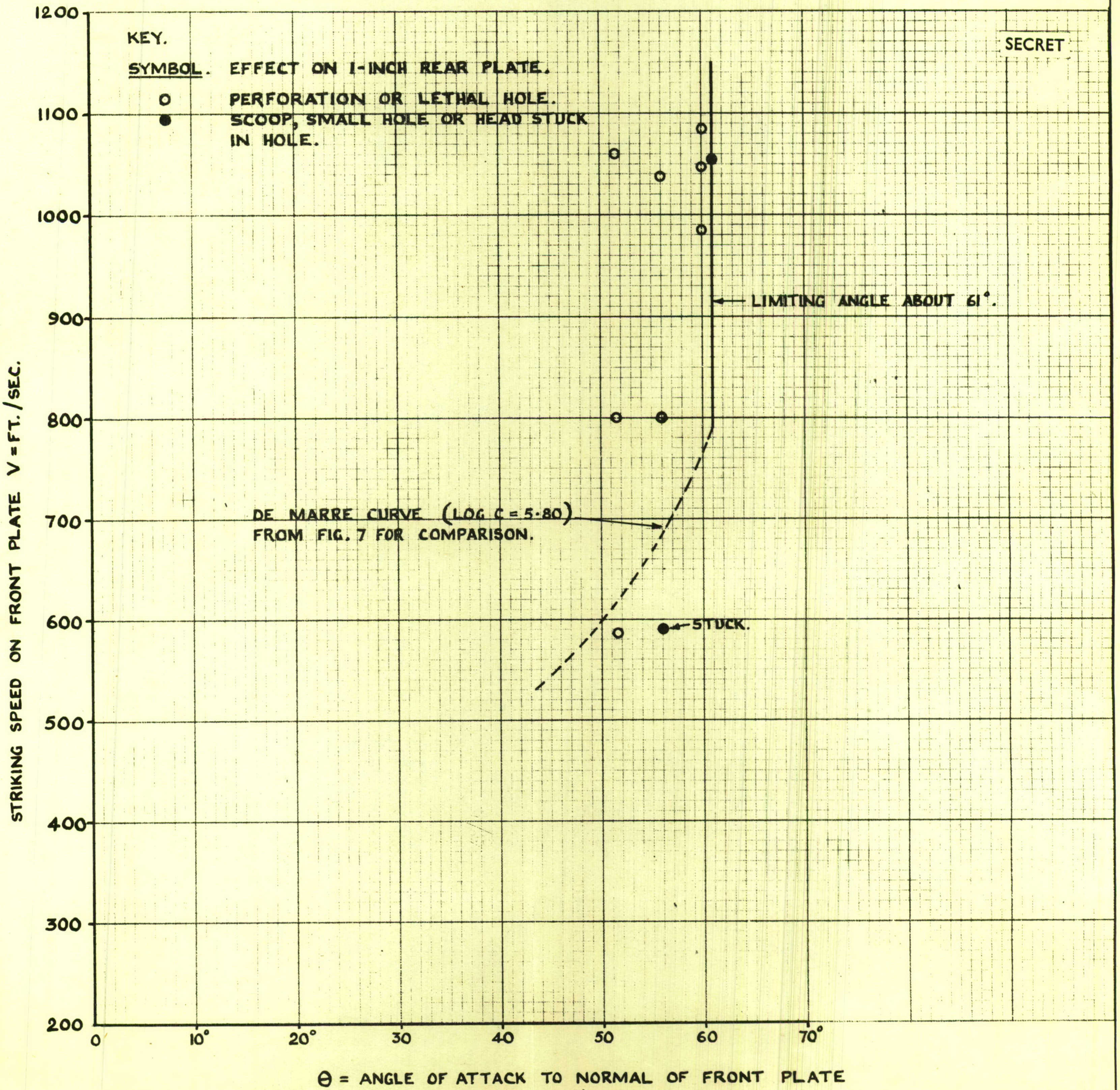
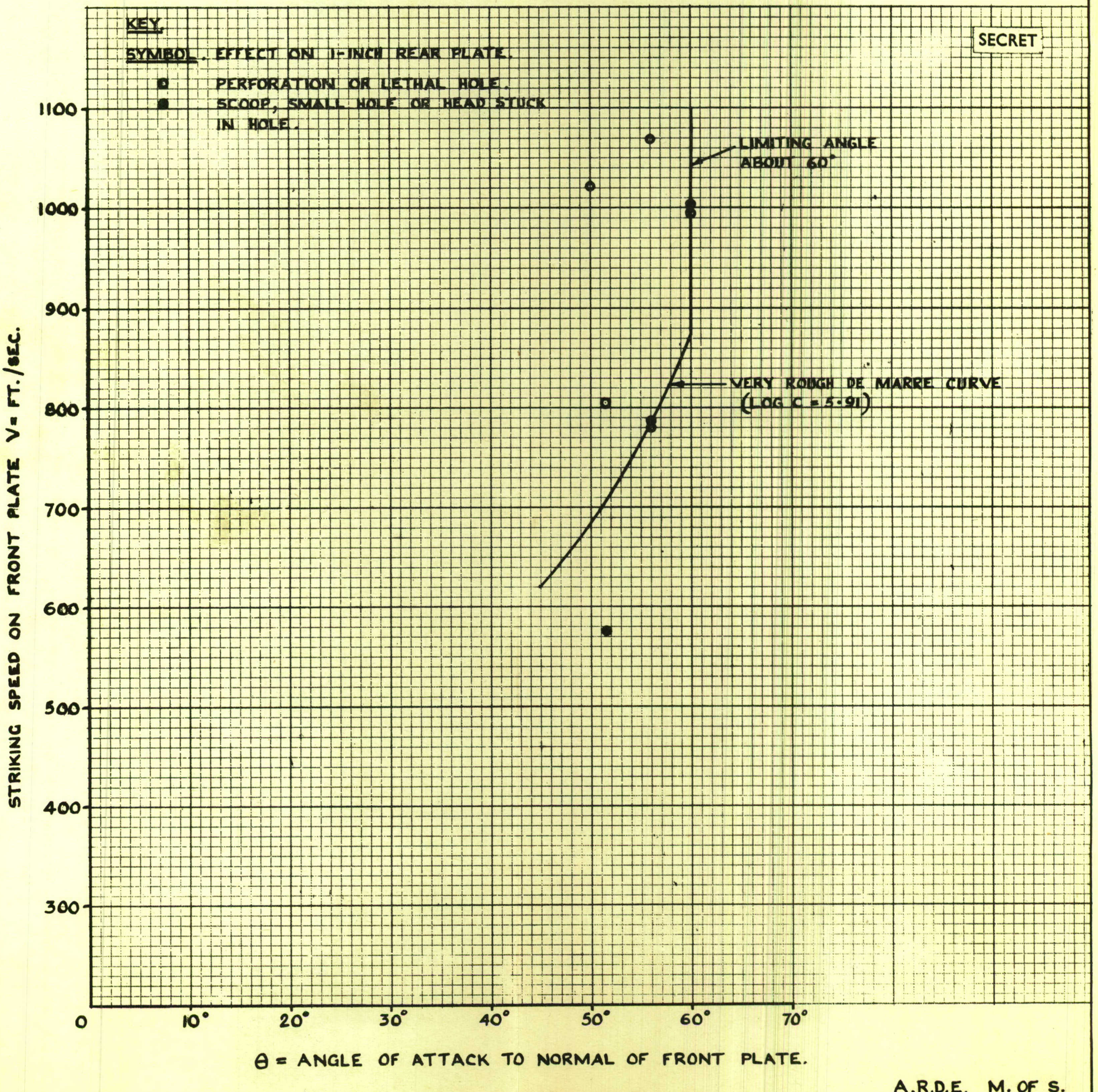
TRIAL	HEAD	TARGET	CURVE REPRESENTS	
1953/54 (TABLE 3)	TYPE D IN STA - 10 STEEL	COMPLETE DOUBLE TARGET	(i) LIMITING ANGLE FOR LETHAL DAMAGE. (ii) DE MARRE CURVE AS IN FIG. 7 FOR COMPARISON.	FIG. 8



A.R.D.E. M.OF S.

TRIAL	HEAD	TARGET	CURVE REPRESENTS	FIG. 9
1953/54 (TABLE 4)	FIG. 4	COMPLETE DOUBLE TARGET	LIMITING ANGLE AND ROUGH CURVE FOR LETHAL DAMAGE.	



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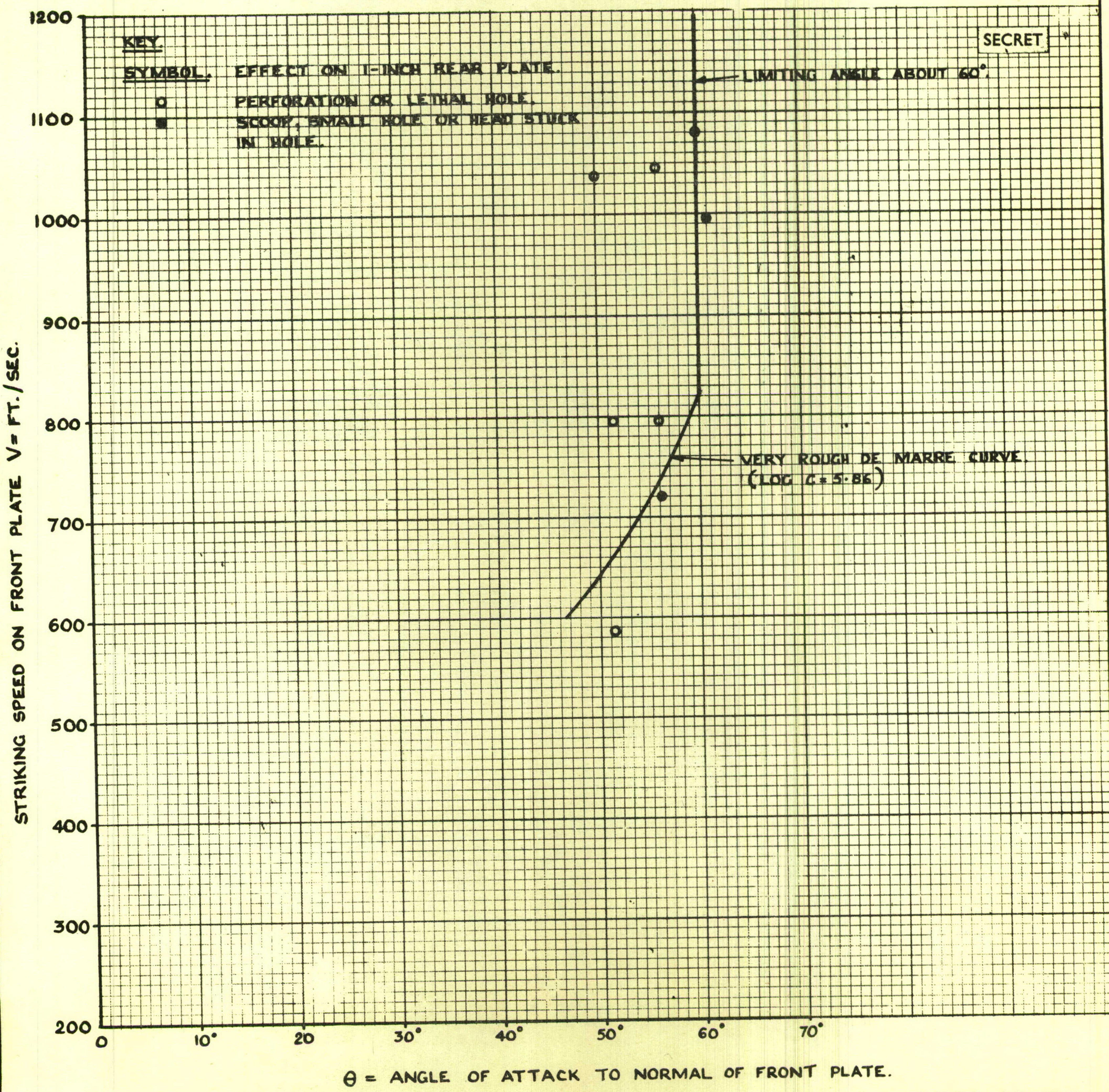
TRIAL	HEAD	TARGET	CURVE REPRESENTS	FIG. 10
1953/54 (TABLE 4)	FIG. 5 WITH HARDENED STEEL CAP.	COMPLETE DOUBLE TARGET	LIMITING ANGLE AND ROUGH CURVE FOR LETHAL DAMAGE.	



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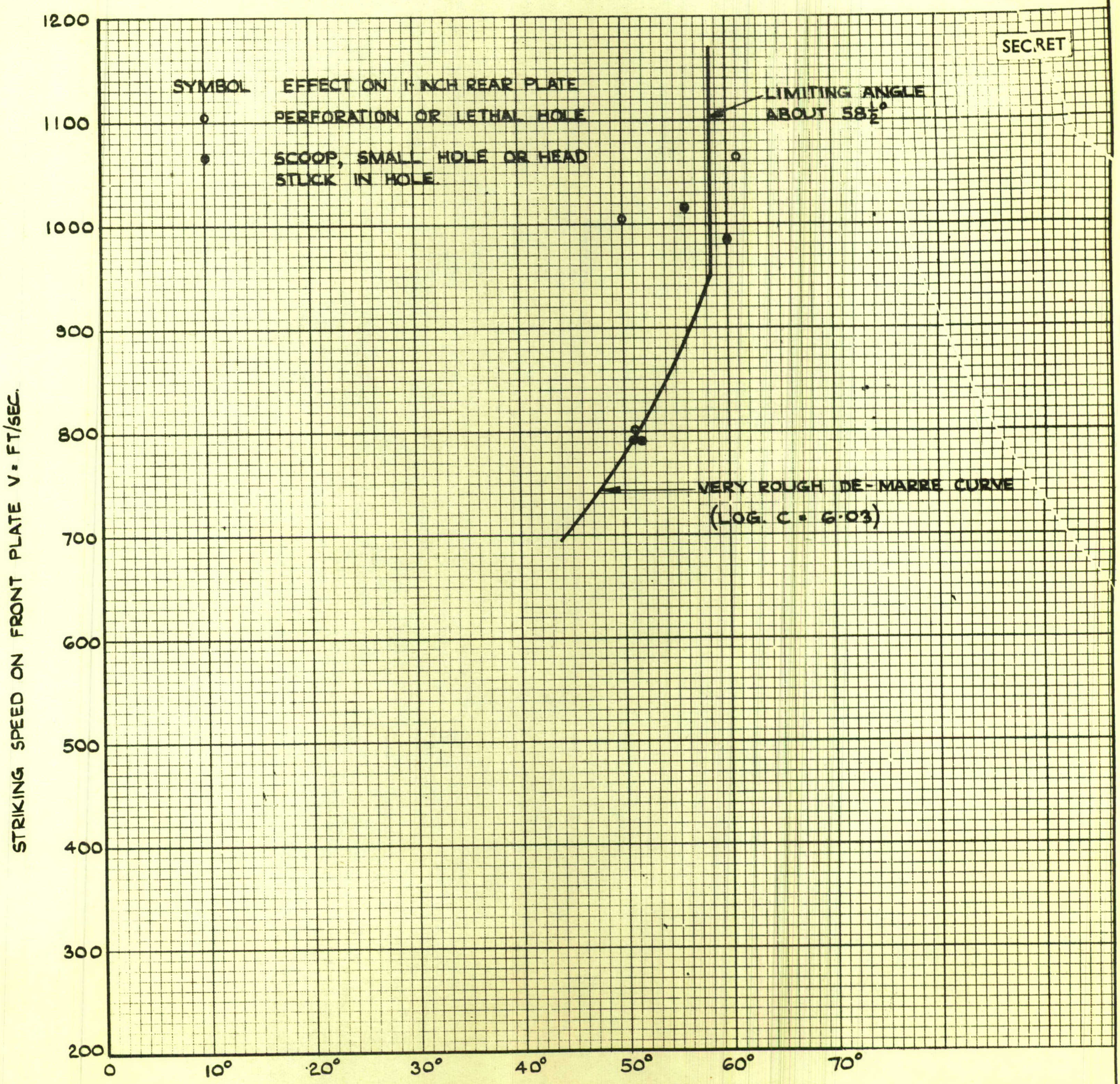
TRIALS	HEAD	TARGET	CURVE REPRESENTS	
1953/54 (TABLE 4)	FIG. 5 WITH CAST STEEL CAP.	COMPLETE DOUBLE TARGET	LIMITING ANGLE AND ROUGH CURVE FOR LETHAL DAMAGE.	FIG. 11



θ = ANGLE OF ATTACK TO NORMAL OF FRONT PLATE

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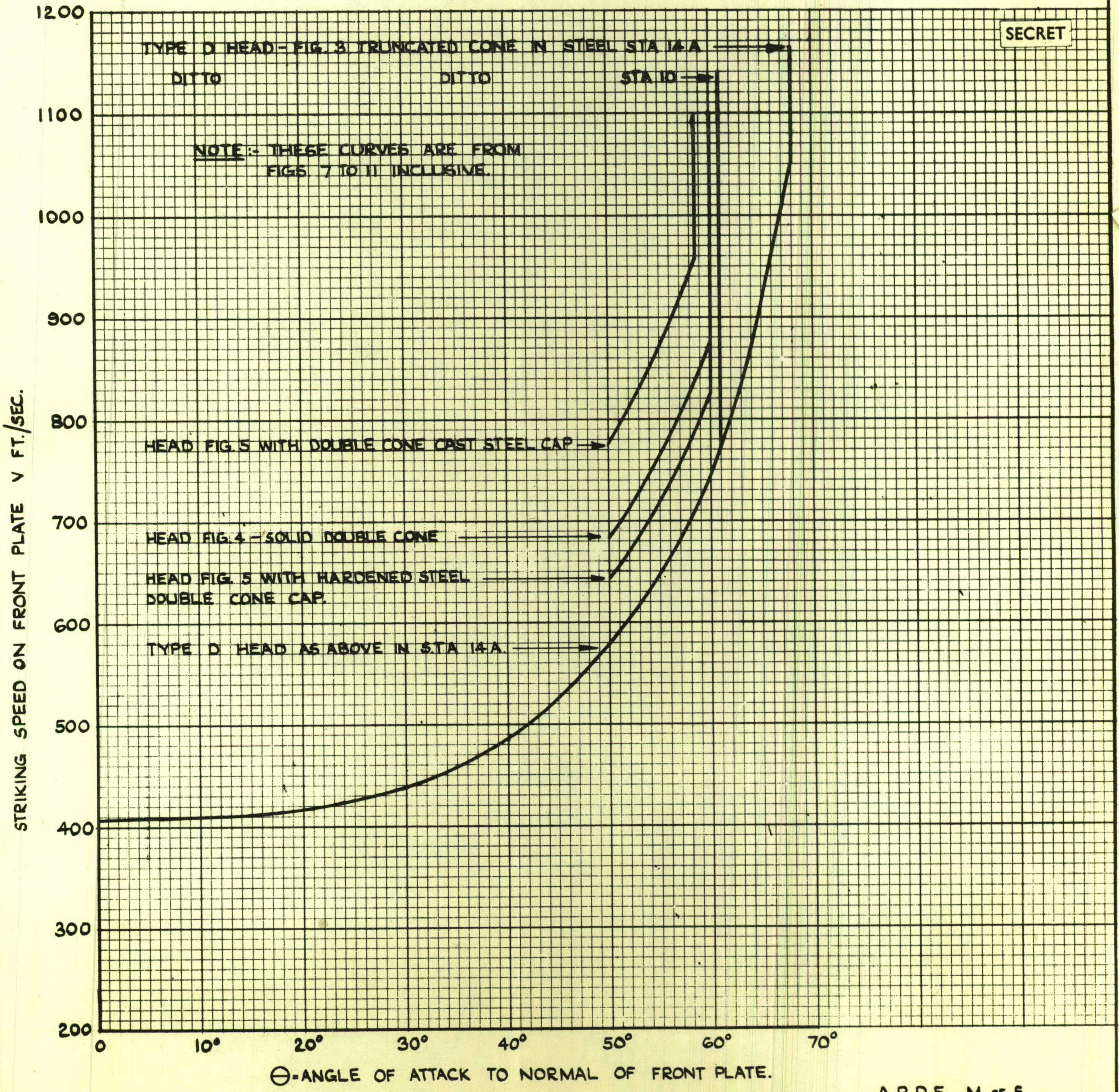
TRIALS	HEADS	TARGET	CURVES REPRESENT	
1953/54 TABLES 1 To 4.	ALL (EXCEPT FIG. 5 WITH MILD STEEL CAP).	COMPLETE DOUBLE TARGET	LIMITING ANGLES AND CRITICAL STRIKING SPEEDS FOR LETHAL DAMAGE TO COMPLETE TARGET.	FIG. 12



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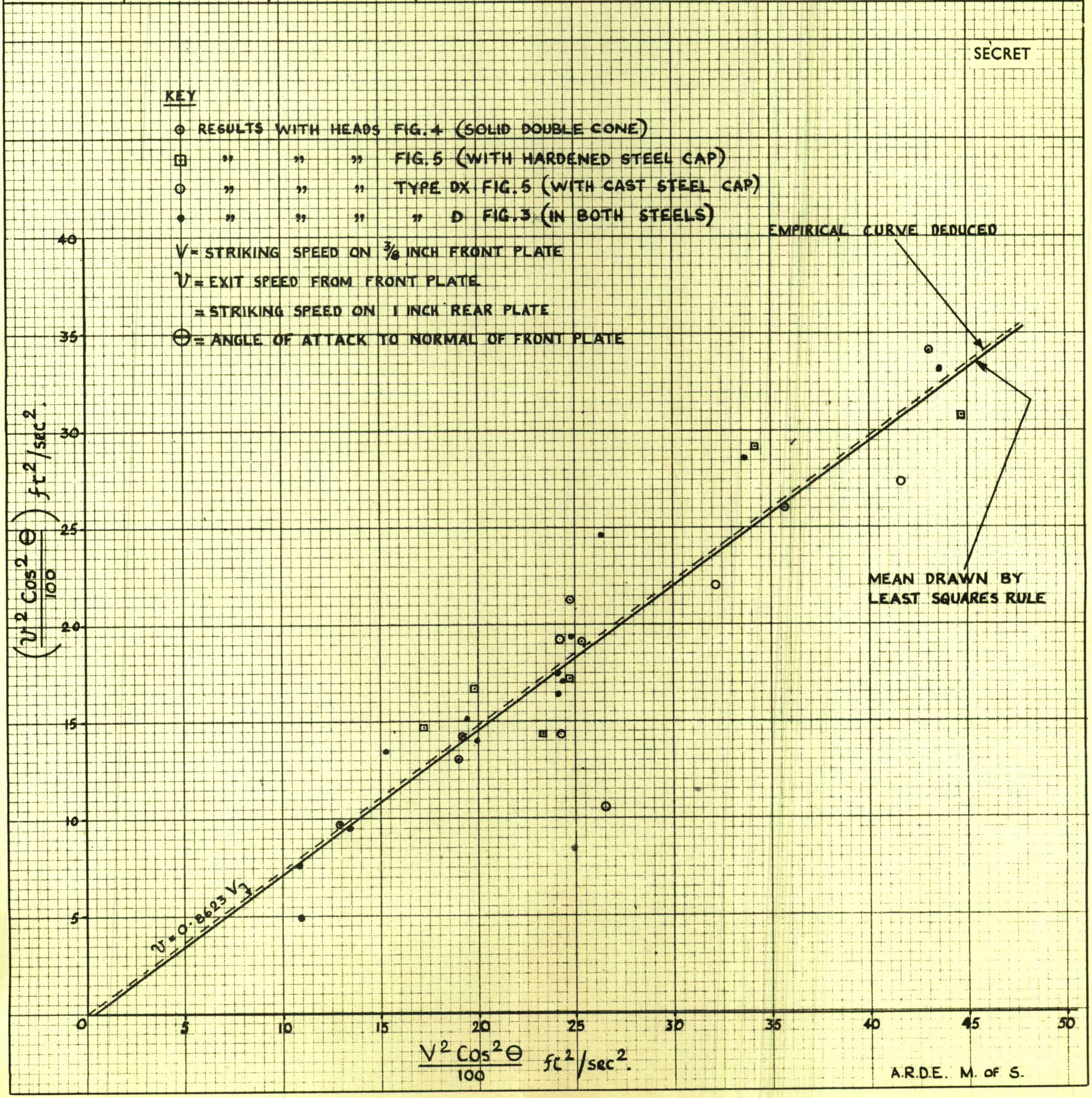
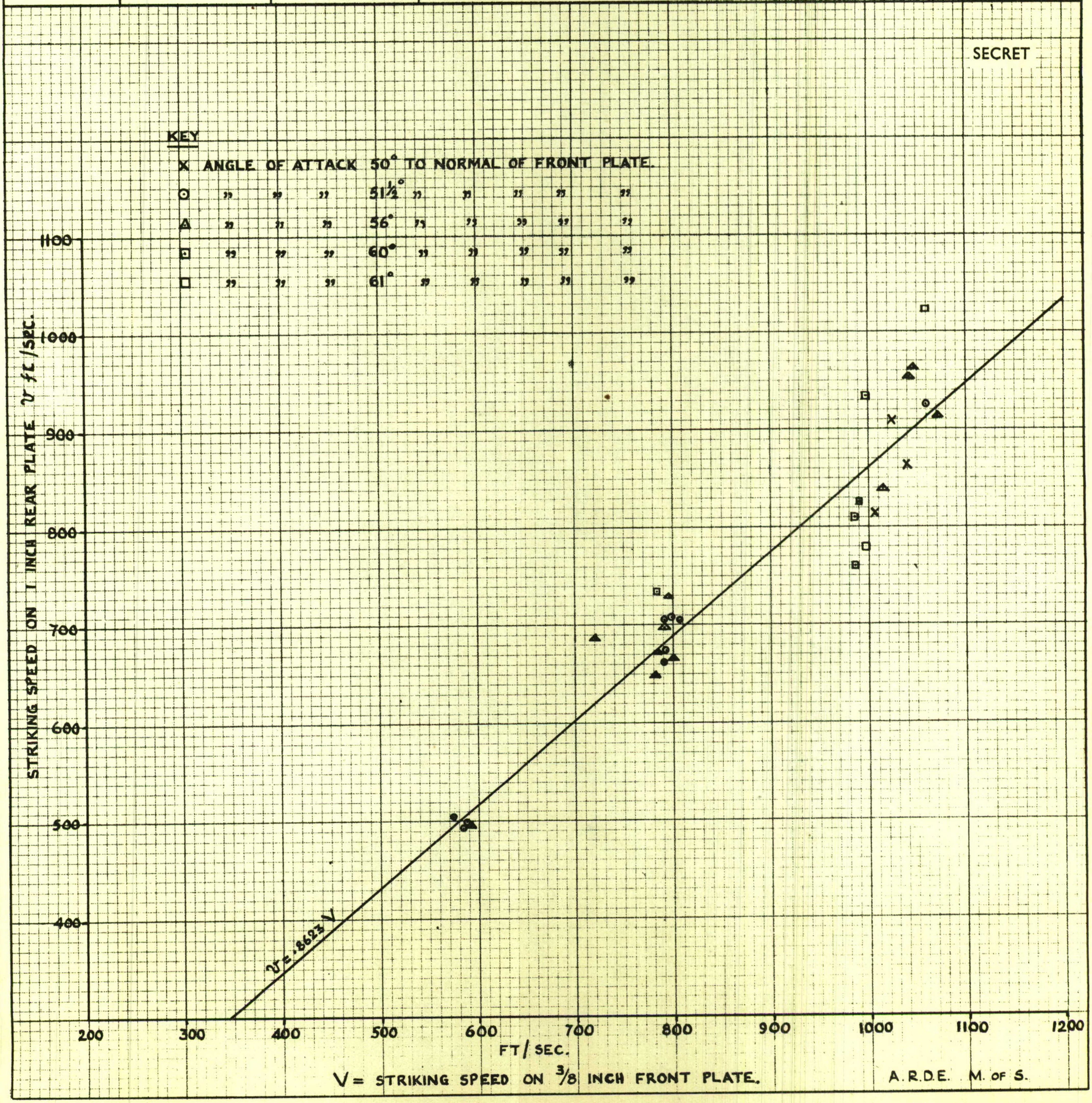
TRIALS	HEADS	TARGET	GRAPH REPRESENTS	
1953/54 (TABLES 1-4)	ALL EXCEPT FIG.5 WITH MILD STEEL CAP.	COMPLETE DOUBLE TARGET	RELATION BETWEEN $\frac{\mathcal{V}^2 \cos^2\Theta}{100}$ AND $\frac{V^2 \cos^2\Theta}{100}$	FIG. 13

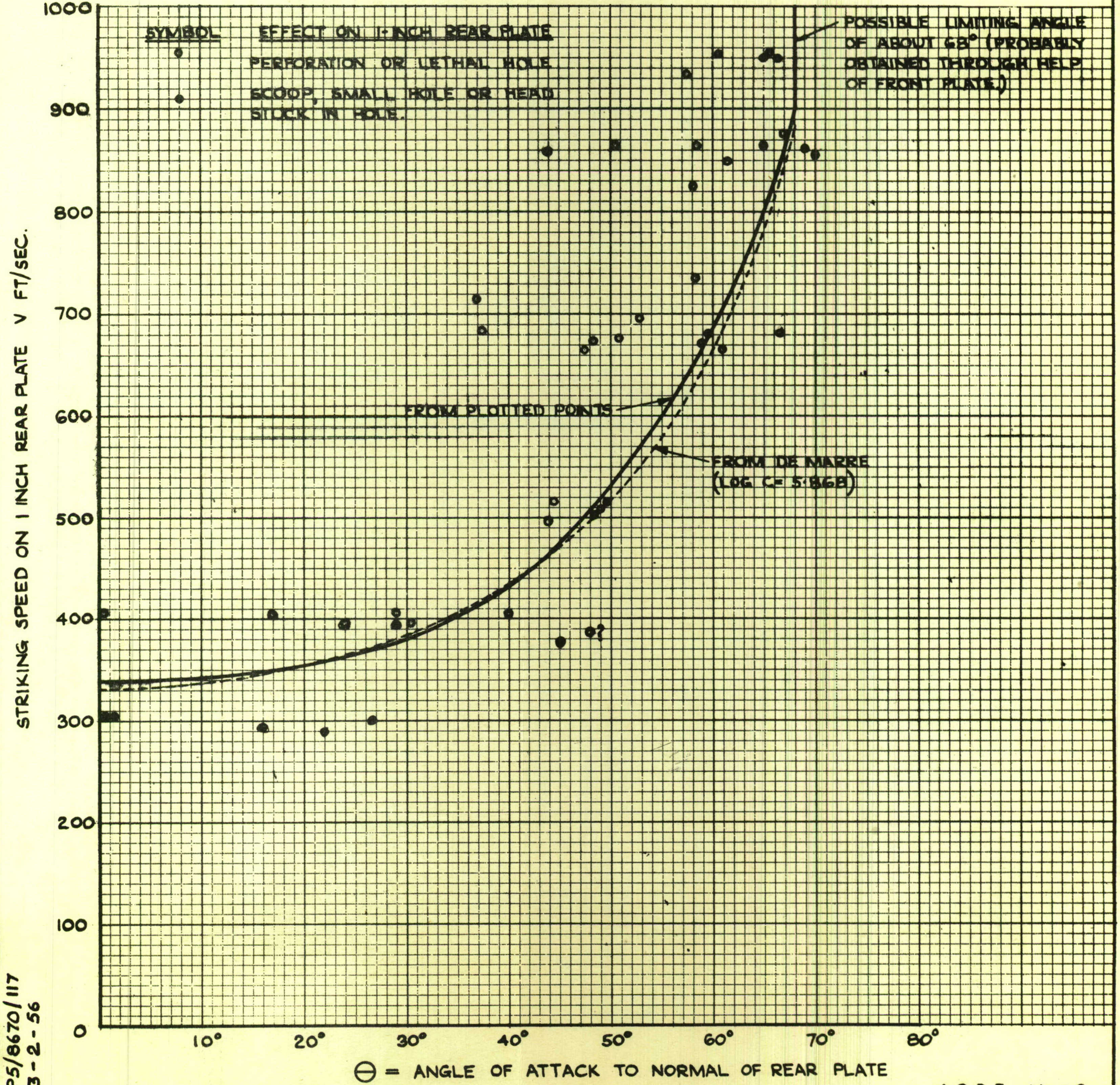


TRIALS	HEADS	TARGET	GRAPH REPRESENTS	
1953/54	ALL	COMPLETE DOUBLE TARGET	RELATION BETWEEN STRIKING SPEED V ON 3/8 INCH FRONT PLATE AND STRIKING SPEED v ON 1 INCH REAR PLATE	FIG. 14



TRIALS	HEAD	TARGET	CURVES REPRESENT	
1953/54 TABLE 2	TYPE D IN STA 14 A STEEL	COMPLETE DOUBLE TARGET	CRITICAL STRIKING SPEEDS AND ANGLES OF ATTACK ON 1 INCH REAR PLATE FOR LETHAL DAMAGE.	FIG. 15

SECRET



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